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A STUDY OF THE COSTS AND BENEFITS ASSOCIATED WITH AVM

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16. Abstract

Automatic Vehicle Monitoring (AVM) Technology has long been perceived as a means of increasing the efficiency and productivity of transit operations as well as that of other users such as police and taxi. This study seeks to examine the economic viability of AVM for a range of users and their unique applications. The report examines other installations throughout the North American Continent and Europe to extract empirical evidence needed to substantiate cost saving possibilities both for single and multiple user applications.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
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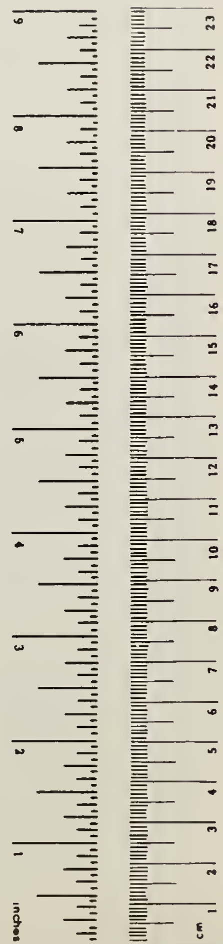
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inchss	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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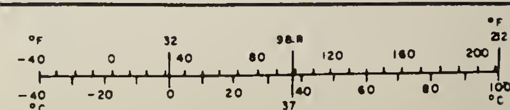

PREFACE

This study of costs and benefits for AVM was conducted at the U.S. Department of Transportation, Transportation Systems Center, in Cambridge, Massachusetts. The study is a small part of a larger UMTA funded project dealing with Automatic Vehicle Monitoring (AVM) technology.

Personnel of the TSC AVM project office and others who have participated in related projects were most helpful in providing timely information. They include: Mssrs. Blood, Kliem, Ow, and Priver; and Mssrs. Goeddel and Cooper.

Particular gratitude is due to those who put in late and early morning hours to complete this study within the given time limits. Without the herculean efforts of Mary Roos, Michael Wolfe, Ron DiGregorio, and Jan Lanza,who patiently provided the technical typing, this report would not exist.

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EXECUTIVE SUMMARY AND CONCLUSIONS

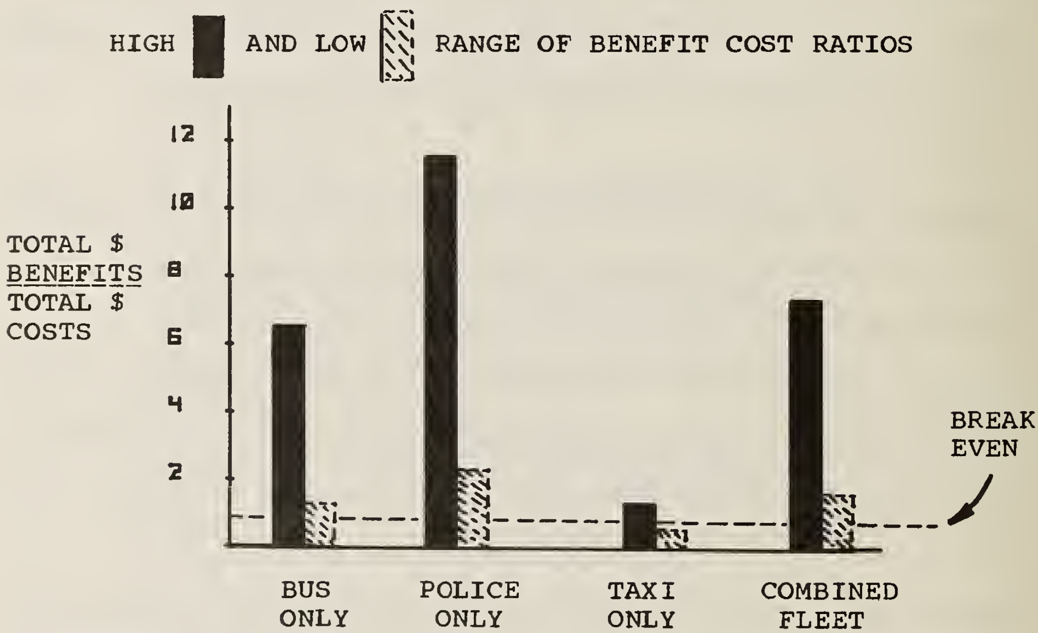
Automatic Vehicle Monitoring (AVM) systems provide real-time vehicle position location information, thus enabling managers to apply more exacting fleet deployment and control strategies. Successful implementation of such controls can permit either service improvements or cost reductions thus producing increased operating efficiency. However, realization of potential benefits is critically dependent upon the willingness and the capacity of operating managers to exploit fully the capabilities of an AVM system.

This study was conducted within the Transportation Systems Center (TSC) in support of UMTA's evaluation of the engineering and operational practicalities of AVM. As a result, the benefit-cost analysis focuses strictly on AVM and does not address potential payoffs of less sophisticated and less expensive alternative fleet control systems.

The core of this analysis is a newly developed computerized benefit-cost accounting model. The model calculates the total life cycle costs of alternative AVM location systems, then determines the dollar value of cost reduction benefits made possible through use of AVM's real-time position location information. The model calculates the costs and

benefits which would accrue to bus, police, and taxi operators in any metropolitan area.

Many uncontrollable variables and uncertainties lie between this study and the real-world impacts of a large scale AVM system. Because of this uncertainty, the study presents two sets of benefits, low and high, based respectively on conservative and reasonably optimistic projections.



Both sets of benefits rest on a combination of hard data and professional evaluation, and neither the high nor the low benefits can be assigned greater liklihood than the other in the absence of more extensive applications data. The range of benefits gives a representative appraisal of uncertainty,

and does not risk masking uncertainty with questionable precision in establishing "most likely" estimates.

The sensitivity of study results, conclusions to variations in key assumptions, and system descriptions were examined with the computer model.

All calculations and results are directly dependent upon input system descriptions and particularly the cost estimates of alternative location systems. This point carries special significance in light of the study's assumption that all competing location systems meet a uniform performance standard.

The AVM benefit-cost analysis concludes that:

- AVM installations to date have not assigned importance to formalized cost-benefit related data gathering or analysis.

- Police cost savings are the most significant - Due primarily to the high cost of staffing patrol cars, even small reductions in required vehicles account for large payroll savings.

- Bus savings are considered positive - However, approximately half of the total savings are made possible by linking automatic passenger counters with AVM in order to replace manual schedule checkers. AVM bus savings vary widely between cities due to extreme differences in operating cost factors such as insurance, O&M, number of checkers and service operating characteristics of transit properties.

- Taxi operator savings do not exceed system costs - Limited payroll savings accompany vehicle reductions because drivers are paid strictly on a commission basis.

- Sharing costs among a mix of users does not provide significant savings - Only one quarter of AVM costs are eligible for sharing between users. In addition, different location systems are the most economical for fixed and random route fleets. The benefits of shared costs are diluted when participants compromise otherwise lower individualized technology costs.

- Costs and benefits are highly dependent upon site and fleet characteristics - Implementation planning must consider the changes in location system costs associated with changes in fleet size, mix or utilization, and operating areas.

- Security benefits of the silent alarm are important - No dollar value has been assigned to these benefits, but they appear to provide sufficient reason to proceed with an AVM implementation which might be marginal in terms of dollar benefits.

- Unusually careful planning and management are required to exploit AVM's potential benefits - The high and low assumptions used in this study illustrate that the extent of savings can vary greatly with slight changes in AVM utilization.

I. INTRODUCTION

AVM (Automatic Vehicle Monitoring) systems provide an information gathering and processing tool for the centralized management and control of urban vehicle fleets. Successful application and operational exploitation of AVM technology may yield significant improvements in fleet productivity, efficiency, and schedule reliability for bus systems, taxi companies, police forces, and other urban fleet operators. Because of this potential, UMTA and TSC are exploring the technical, operational, and economic feasibility of AVM.

This benefit-cost analysis is part of the overall UMTA/TSC evaluation of AVM. The study looks beyond field experimentation and focuses on the probable costs and achievable benefits of an AVM system fully deployed in a major metropolitan area. A comprehensive analysis of the literature and AVM-related experience in the U.S., Europe, and Canada have been integrated with additional research here at TSC to develop a computerized cost-benefit model. The model is a management tool which accounts for the total life cycle costs and benefits for any AVM system. Because of this, it is useful for a wide range of AVM sensitivity analyses; for studies of particular AVM programs; and with

minimal adjustment, for the analysis of other technical or management innovations which address transportation operating efficiencies.

The model approaches costs in terms of four generic AVM location systems. The cost factors for the generic systems have been developed by TSC's AVM Project Office, and the operational analysis and model building were accomplished within the Transportation Management Research Branch, under the Office of Systems Research and Analysis. Benefits are defined within the model as cost reductions made possible by increased operating efficiency; <u>levels of service to the public are held constant</u>. The study addresses AVM utilization by bus, police, and taxi operators, and by a cost sharing multiple user fleet sharing total costs. The impact on the study results of key assumptions and data inputs is explored by means of sensitivity analysis.

Chapter II of the study defines AVM, lists all the claimed benefits, and discusses previous research and actual field experience with AVM systems. Chapter III explains the concept, structure, and assumptions of the model; it explains the logic which in the end defines the results of the study. Chapter IV presents AVM deployment costs and reviews the sensitivity of location system cost rankings to

differences in fleet size and area. Chapters V and VI discuss AVM payoffs and the sensitivity of those payoffs to the dimensions of the model and the base case fleets. Chapter VII concludes with a review of those benefits which were not converted to dollar values.

II. AVM TECHNOLOGY, BENEFITS, AND EXPERIENCE

2.1 AVM Systems Description

An AVM system maintains a continuously updated file of all vehicle locations in an equipped urban fleet. It consists of a central computer facility to coordinate and manipulate real-time data as it is collected; a two-way communication system for digital and voice data; and a means of specifying vehicle location. The data processing system offers the opportunity to add on a computer-assisted dispatch system and to report transit emergencies directly to police headquarters. The communication system supplements traditional voice communication with digital data which can include vehicle status information, such as exact passenger data; silent emergency alarms; and non-voice operating commands from the dispatcher, such as skip-a-stop or pause-at-the-next-stop. However, the most revolutionary element of AVM is the vehicle location subsystem. Continuous current knowledge of vehicle locations provides the information necessary to control and adjust fleet operations on a real-time basis. Put differently, the vehicle location subsystem creates opportunities for more efficient and productive utilization of equipment and personnel.

There are four generic kinds of location subsystems, each of which are defined to meet the basic design specifications of the UMTA/TSC AVM project. The differences between the location systems are summarized below and illustrated in Figure II-1.

Sharp Signpost: This type of system provides precise position location only at particular points. It operates around either a narrow beam optical scanner, a microwave transmitter or magnets imbedded in the road surface.

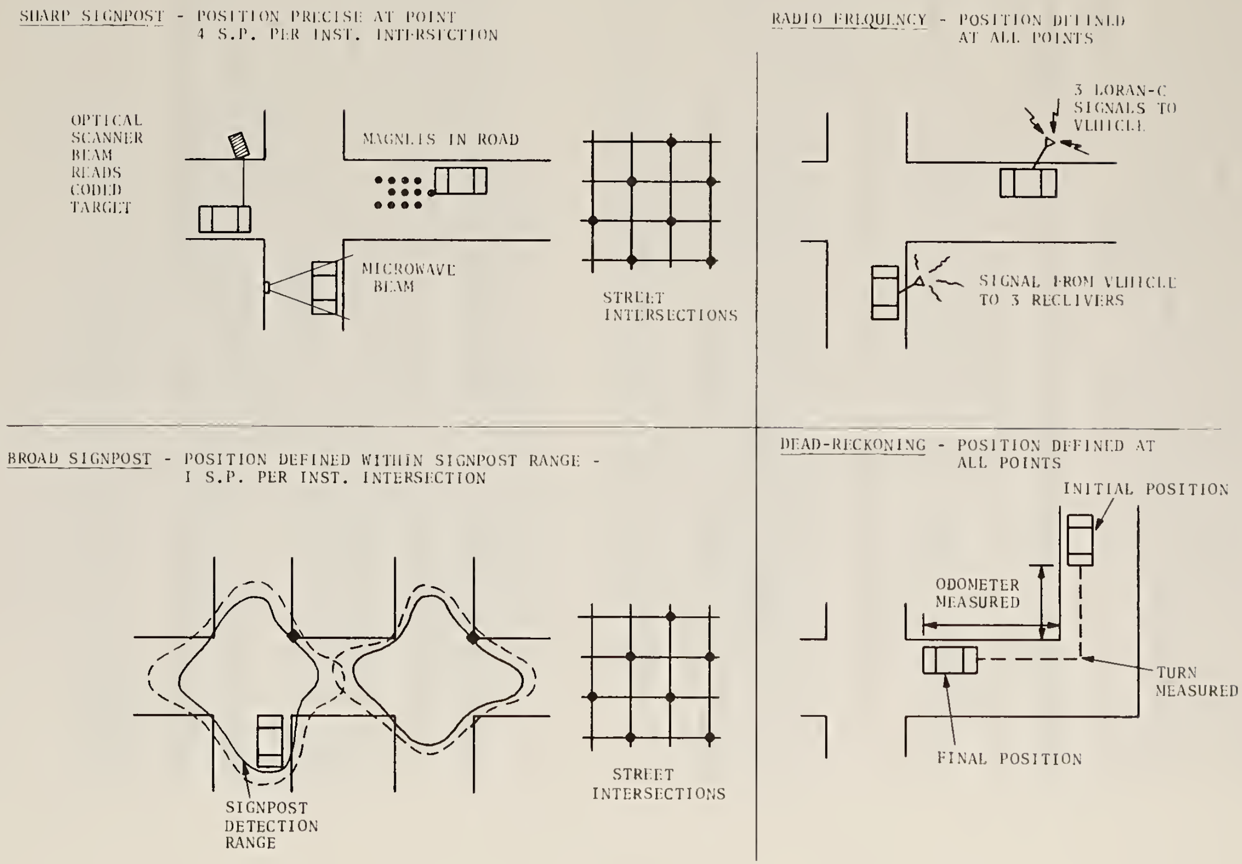
Broad Signpost: This group of systems provides area coverage within a range of 50 to 100 feet of a signpost. Coded radio signals are transmitted from these dispersed signposts to vehicles within their range.

Radio Frequency: These systems (including VLF, pulse trilateration, and AM phase lock) provide position location information at any point within the service area by means of computer-analyzed radio signal triangulation.

Dead Reckoning: Position information is provided at all points within the service area without reference to external signals. Location is determined through a combination of precision odometers and heading indicators.

FIGURE II-1

GENERIC CLASSES OF LOCATION SUBSYSTEMS



The number of manufacturers of these various technologies reflects an extensive comittment to the potential economics of AVM. Their installations and evaluations to date have led them to conclusions that even minor operational improvements justify serious investigations. Consistently positive dollar estimates related to anticipated AVM benefits are reflected in a series of proposals recently evaluated by the TSC AVM project office. Returns on investment (ROI) for even small fleets are estimated to reach payback in 3 to 4 years. The extent of supportive evidence or analyses for such ROI's is unfortunately slim and the paucity of sufficient data to draw statistically sound inferences is repeatedly recognized as justification for rigorous test and demonstrations.

2.2 The Potential Benefits of AVM

AVM systems offer a unique combination of capabilities which in theory offer the means for significant service, management, and economic benefits. This section surveys the range of potential AVM benefits and, in effect, outlines a protagonist's case for AVM. The cost-benefit study as a whole analyzes the probable achievability and value of these claims.

2.2.1 Fixed Route Schedule Adherence. AVM establishes a closed-loop information system which informs a dispatcher of the disposition of his vehicles and permits him to control their deployment according to several strategies. This could yield the following benefits in fixed route transit service:

- Increased on-time service, with buses never early and seldom late.
- More uniform headway adherence on short headway routes.
- More even distribution of passengers between vehicles.
- Reduced layover time due to reduced uncertainty of total travel time. Thus, fewer vehicles and drivers can maintain a given frequency of service on major routes.
- Fewer personnel required to check and control schedule adherence.

2.2.2 Random Route Dispatch Improvements. Closed-loop control capabilities are also available to random route vehicle dispatchers. Here they permit the dispatcher to insure that only the nearest vehicle is used in response to each demand on the system. As a result:

- Average response times to service and emergency calls can be reduced.
- Police can improve coverage with the same mobile cruiser force or can maintain coverage with a smaller force.

- Taxis can reduce the proportion of dead-head miles to revenue miles and thus meet demand with a smaller fleet.

2.2.3 Operating and Management Information. On-vehicle sensors and the communication subsystems permit the collection of complete route and vehicle data according to time and location. AVM system software can compile and analyze this data to provide the following potential benefits:

- Accurate passenger counts by stop and time of day to support optimal scheduling.
- Fewer personnel required to gather and analyze passenger demand and scheduling information.
- Improved management effectiveness and new operating strategies rooted in better historical data.
- Aid in planning and rapid evaluation of new routes.

2.2.4 Silent Alarm. Digital transmission of the vehicle code and exact location in case of emergency offers these benefits:

- Aid to police for quick apprehension of criminals.
- Deterrent effect on criminal activity.
- Improved security and peace-of-mind for passengers and drivers.

2.2.5 Improved Patronage and Farebox Revenue. Most of the AVM benefits discussed above tend to improve the reliability and attractiveness of public transit. Even if there is no increase in frequency of service, the cumulative effect of these benefits should improve ridership and revenue.

2.2.6 Expanded Benefits. AVM may be viewed as a series of modular building blocks which can be varied to suit particular situations. System capabilities can be expanded--at added cost-- to achieve the following kinds of benefits:

- Electronic interaction with traffic light controllers to gain signal priority for late buses.
- Real-time display of schedule status and expected vehicle arrival time for patrons at a major bus stops increasing public confidence in service reliability.
- Expanded on-board sensors to warn dispatchers and maintenance personnel of impending vehicle failures (such as falling oil pressure).

2.3 AVM Operating Experience

Various vehicle monitoring systems have been implemented in Europe and in North America. Sites include Dublin, Hamburg, London, Paris, and Zurich in Europe, and Chicago, Orlando, and Dallas in the U.S., and Vancouver, B.C., and Mississauga, Ont., in Canada.

As categorized in Table II-1 below, the European and Canadian systems were intended primarily to improve the level of transit service, while U.S. applications have been used primarily to enhance public safety.

TABLE II-1. PRIMARY USE AND LOCATION OF AVM SYSTEMS

Service Improvements	Public Safety
Dublin	St. Louis
Hamburg	Chicago
London	Orlando
Paris	Dallas
Zurich	
Mississauga	

It is also possible, as is done in this study, to view AVM as a means of reducing operating costs without reducing service levels.

Unfortunately, none of the systems implemented to date had as a major objective, cost savings through improvement in service operating efficiencies. Whether or not a link can be demonstrated remains conjecture, for regardless of the purpose of these AVM systems, very few have produced consistent empirical data on their operational or financial impacts.

During on-site visitation and through extensive correspondence, transit operators throughout Europe repeatedly stated that AVM was looked upon as a means of improving service reliability. This approach means that excesses in capacity are to be converted into service expansions at no increase in operating costs. In Zurich, when the usage of AVM resulted in a reduction of 12 buses, they were retained for service expansion.

Each European AVM operation is characterized by estimating vehicle location and transmitting location data to a central control station. Hamburg, London, and Zurich employ location data to exercise fleet control via two-way radio communications. In Hamburg and Zurich all AVM equipped buses have passenger counters.

The European AVM benefits perspective derives from their views that bus transportation is an urban necessity, a public utility, and an integral component of the services provided by municipal governments. Even the integration of a silent alarm capability with AVM is of lesser importance as transit crime is virtually non-existent in Europe. Utilizing AVM related information to revise schedules is not considered either, as their schedules, while they may vary by time of year, are generally not revised.

AVM does provide the means for better fleet control to keep vehicles on schedule and thus provide better service. The beneficial aspect of such control is increased ridership, and while Hamburg and Zurich have reported systemwide patronage increases, it is unknown whether these increases were greater for AVM equipped than non-AVM equipped routes, as no formal data gathering was planned.

The St. Louis Metropolitan Police Department conducted extensive tests with a dead-reckoning AVM system in District 3, with 35 instrumented cars. The primary objective was to demonstrate quicker response times, and, in 9 out of 11 months, travel time to respond to calls was significantly shorter. Over the entire 11 months, travel time saved was approximately 1/2 minute out of an average of 5 minutes. Dispatch times were expected to increase due to a greater work load, and while they initially did increase, they ultimately were down 1.4% on the average following a short learning period. The police department estimates total time savings at 15%, and is proceeding with citywide implementation on that justification.

Chicago Transit Authority (CTA) installed a broad signpost system with a silent alarm for the prime purpose of improving security on board transit vehicles. They have

recorded information on time-point passage, but make no attempt to apply headway control. The property management is quite satisfied with the crime reduction aspect of AVM and wishes to expand the coverage. Since control was not attempted in Chicago, there is no data on the value of improvements such as load factor or layover reduction...two of the bus benefits postulated in this study. However, AVM has enabled CTA to reduce the number of point-men, mobile supervisors and terminal telephone men, and save the cost of special telephones installed on the streets and at four terminal points for the use of these employees.

In Dublin, a system using two-way radio, manual polling, and voice response from the vehicle operator emulates an AVM system, though it is much more labor intensive. They have, however, gathered data on real-time schedule control, comparing a route using a dispatcher with radio control to a similar but uncontrolled route. Passenger wait time on the controlled route averaged 25% less (.93 minutes) than on the comparable uncontrolled route. This indicates the magnitude of efficiency improvement which can be expected with AVM.

The experience and information attainable from Dublin represent the nearest approach to a deliberate experiment intended to record data for analytical purposes.

While the costs of implementing AVM are well recognized and documented, further installation and investments for the purposes of attaining cost savings with AVM will not be convincingly justified without a well designed and controlled period of real-world experimentation.

III. THE STRUCTURE AND ASSUMPTIONS OF THE BENEFIT-COST MODEL

The heart of this analysis is a TSC computer model which converts technical, operational and financial information into cost and benefit dollar totals for a specific AVM deployment. The logic and assumptions of the model have a significant impact on the study results; indeed, they define those results. While the next three chapters examine in detail the costs and benefits of AVM and the sensitivity of the results to changes in specific data inputs, this chapter presents an overview of the model, summarizing its key methods and assumptions. Appendix A supplements this chapter by listing and justifying all data entries and parameters used in the base case calculations.

The TSC AVM model is a computational tool which runs in sequential cost and benefit modules. As Figure III-1 illustrates, the cost module converts AVM cost elements, such as terrain, area, and fleet characteristics into total life cycle system costs. The benefit module, as shown in Figure III-2, first factors AVM impacts against fleet operational and financial data to compute cost avoidance benefits, and then compares the benefits with system costs. This model is not a monte carlo or gaming simulation which

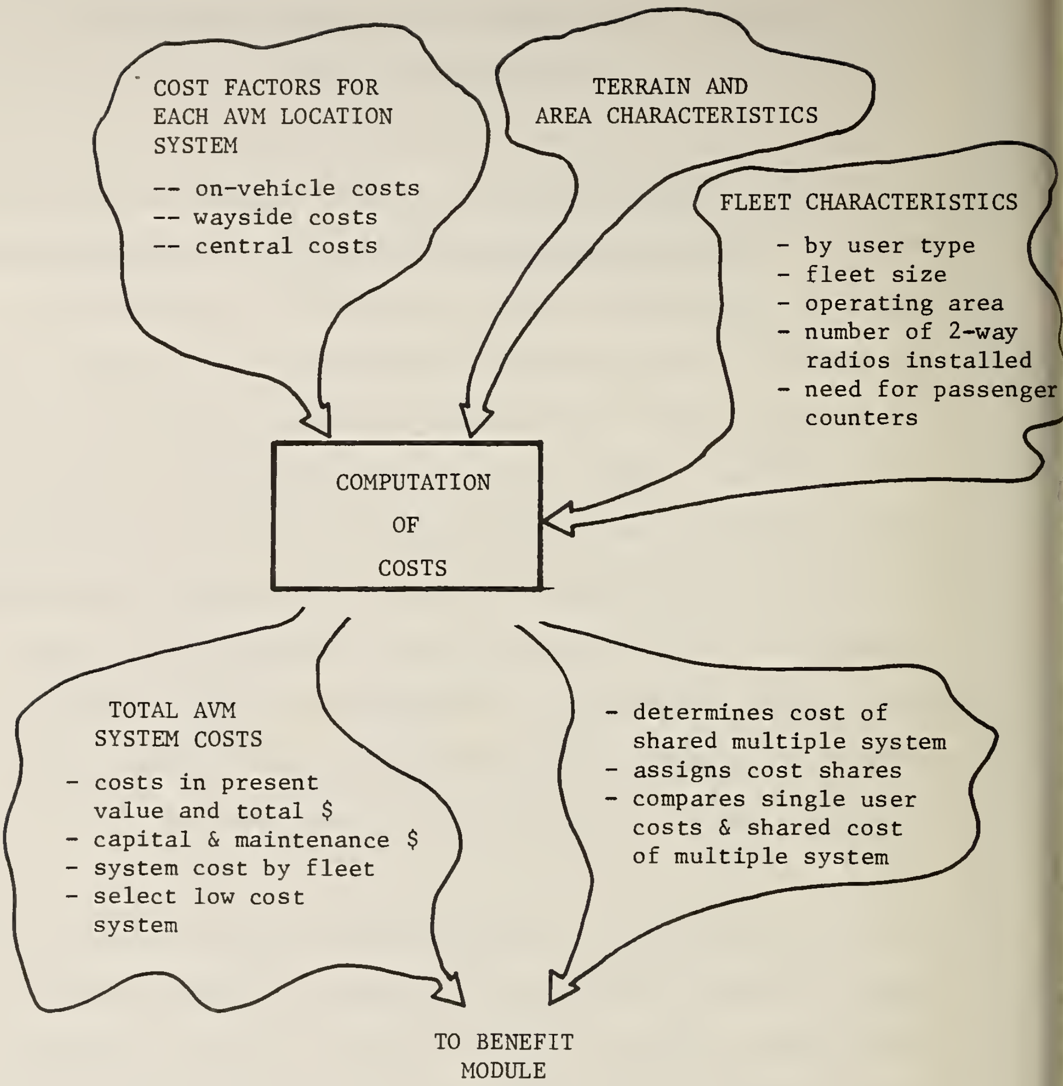


FIGURE III -1

AN OVERVIEW OF THE COST MODEL

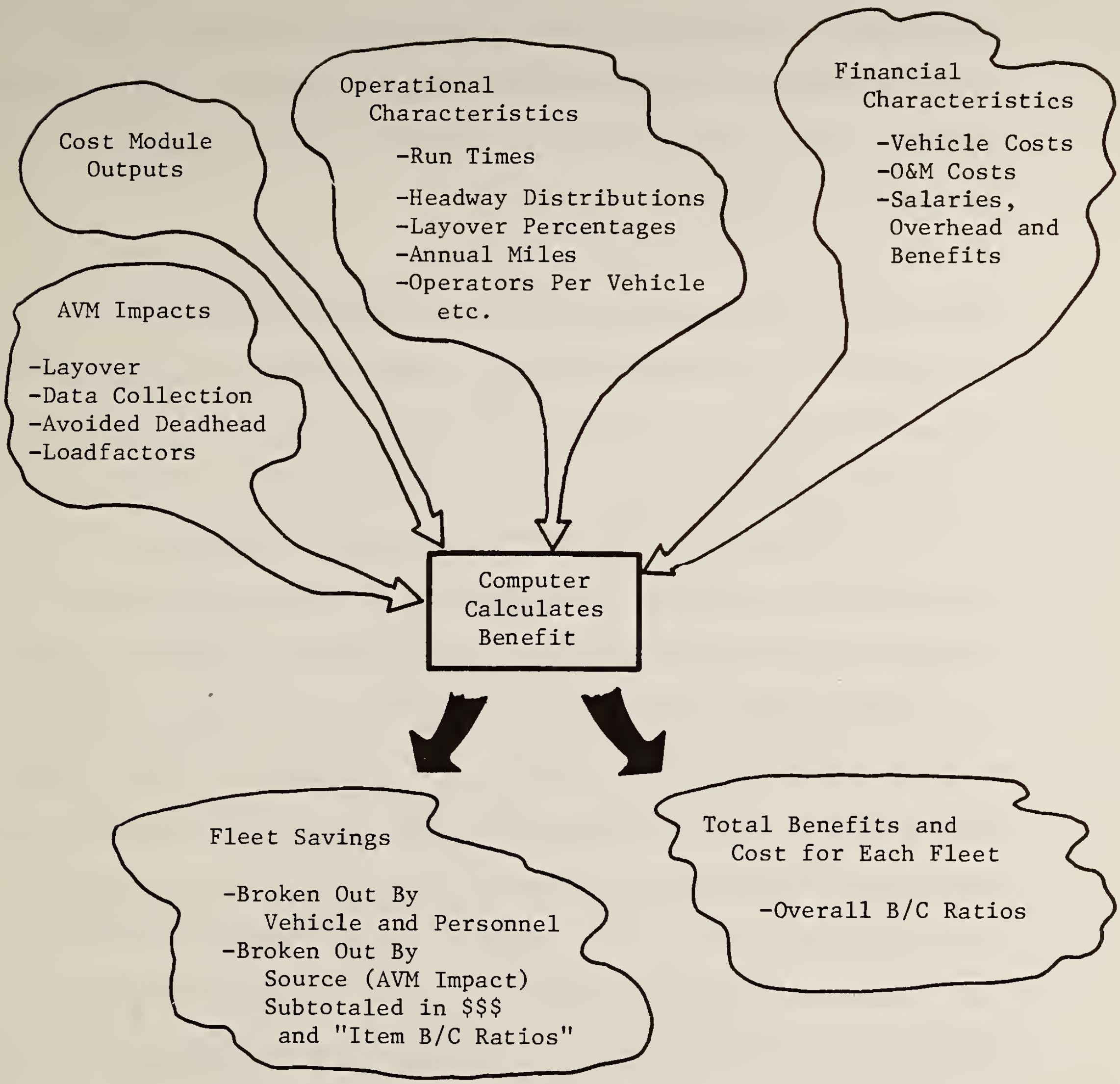


FIGURE III-2

AN OVERVIEW OF THE BENEFIT MODULE

determines the operational effectiveness of AVM; it is sophisticated accounting device which requires specific AVM effectiveness estimates as inputs in order to produce meaningful results.

The model, designed for TSC's time sharing computer, is interactive and conversational. Many parameters must be set on every run and the remainder may be changed within the computer program (see Appendix B, Users Manual). The result is an extraordinarily flexible instrument which can accommodate any urban size area and a large number of vehicle fleet combinations. This makes this model useful beyond this particular study since it can analyze any specific AVM project or proposal. In fact, it can be used with minimal effort for benefit-cost analyses of almost any innovation designed to improve transportation efficiency.

3.1 The Base Case AVM System

The purpose of this study is to determine the benefit and cost tradeoffs for a fully deployed AVM system in a major metropolitan area. In order to accomplish this it was necessary to specify the parameters of such a system, which would become the base case or reference system. The base case is an abstraction similar to the geography, fleet sizes, and service characteristics of a large city such as

Los Angeles. Chapter VI examines the sensitivity of the study results to these parameters and offers insight into the application of the results to other urban areas.

3.1.1 Vehicle Fleets. The study results reflect operations of three different fleets: 2,400 buses which operate throughout the metropolitan area and 1330 police patrol cruisers plus 800 taxis which operate only in a central core area. Demand responsive Dial-A-Ride fleets were included in the early analysis but eliminated from the base case due to very poor returns on AVM investments. However, the TSC model contains both Dial-A-Ride and general subroutines which may be used for follow-on studies of Dial-A-Ride or other fleets such as ambulances, fire apparatus, cement trucks, commercial delivery fleets, etc.

3.1.2 Service and Operating Area. The overall service area, illustrated in Figure III-3, is 5,000 square miles bounded by an imaginary line connecting the tips of the radial bus routes. Within this service area is a central core of 475 square miles served by the police, taxi and bus -- that is, by both random and fixed route fleets. The buses operate over 3,825 route miles, of which 2,647 are outside the core area. Terrain in the entire area is classified as rugged due to canyons and defiles. This

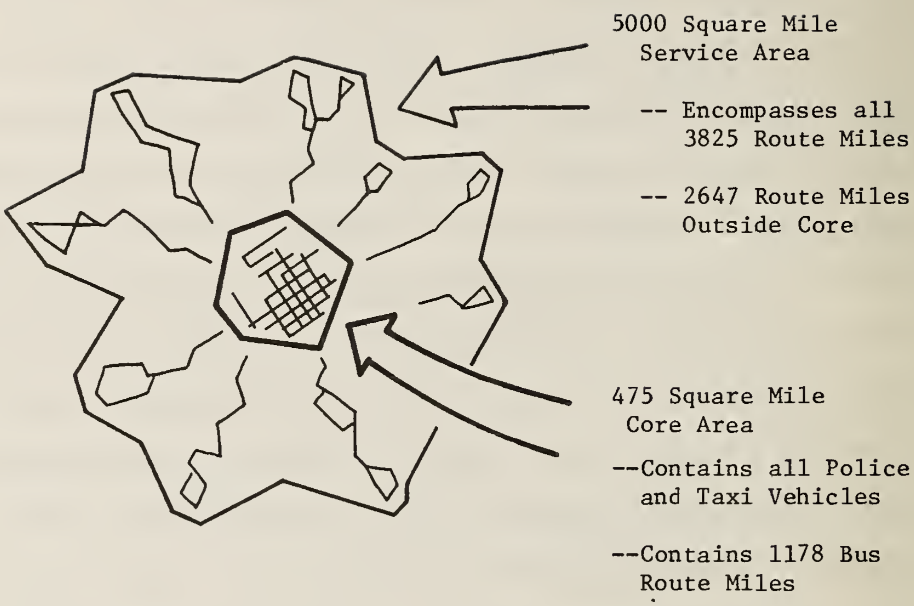


FIGURE III-3

THE BASE CASE OPERATING AREA

causes the model to augment certain categories of AVM wayside equipment costs as would be required to insure high quality communications.

3.1.3 Deployment Scenarios. Within the base case, costs and benefits are developed for four different deployment scenarios, that is, for four different user fleets. Three scenarios represent the independent bus, police and taxi AVM systems. The fourth scenario represents a utility-type multiple-user AVM system with the bus, police and taxi operators sharing common infrastructure costs. The model calculates complete cost and benefit totals for each scenario.

3.2 AVM Cost Calculation Approach

3.2.1 AVM Components. The study determines the system costs and benefits for a core AVM system (location, computer and digital/voice communication subsystems) plus silent alarm and passenger counters. Neither costs nor benefits are included for AVM "accessories" such as bus stop passenger information displays, traffic light actuators, or vehicle mechanical status indicators. Beyond this, the model accumulates only costs and benefits greater than those associated with comparable non-AVM equipped fleets. Put differently, a radio-equipped non-AVM bus fleet establishes

the zero cost and zero benefits bases against which the AVM-equipped bus fleet is compared.

3.2.2 Passenger Counters. Bus managers may choose to equip all or a portion of their fleets with passenger counters. If all vehicles are equipped, the property will gain the capacity to measure and record all passenger service utilization by route, stop, and time of day, and may be able to use this information on a real-time basis to adjust service in response to unexpected surges of demand. However, considerable expense can be avoided if the managers choose to equip only a portion the fleet, collect samples of service utilization data, and adopt less sophisticated measures to accommodate unexpected demands. The base case bus fleet assumes that 120 passenger counters are purchased, enough to equip five percent of the fleet. This provides two counter-equipped buses for each of the current total of sixty manual checkers, and it enables bus managers to collect sample data which is at least as good as the present manually produced data.

3.2.3 Generic AVM System Costs. AVM deployment costs have been developed from proposals submitted to the Department of Transportation in October 1975 by eight contractors seeking to install a multiple user AVM demonstration system in Los

Angeles. The proposals covered equipment, programming, installation, calibration, and maintenance for various fleet sizes. The data in the proposals have been analyzed by TSC's AVM Project Office, which established the four generic classes of location system (sharp signpost, broad signpost, radio frequency, and dead reckoning). This was done to describe and categorize the proposals, and then identify representative cost factors and their variations for each generic class of systems in terms of on-vehicle equipment, wayside equipment and central computer and communications equipment. Using these cost factors, as specified for 1,000 vehicle fleets,* the benefit-cost model sizes the AVM system for the base case: service area; number of route-miles; and number of vehicles. It then sums the capital costs, and computes the maintenance expense.

Benefit-cost ratios are, by definition, directly sensitive to cost totals, and the base case AVM costs are only as dependable as the data in the eight proposals. In the judgement of the TSC AVM Project Manager, the estimates in the proposals are realistic, the best available, and at this

*Since most fleet combinations in the base case exceed 1,000 vehicles, use of the 1,000 vehicle criterion costs may understate potential economies of scale associated with a nationwide implementation of transit, police, and taxi fleets.

point in time they remain dependable within the following limits shown in Table III-1 below.

TABLE III-1. TOTAL SYSTEM COST VARIATIONS IN GENERIC AVM SYSTEMS

Sharp Signpost	± 20%
Broad Signpost	± 5%
Radio Frequency	± 18%
Dead Reckoning	±6.5%

The impact of changing system costs will be addressed when AVM benefits are compared to the different location system costs in Chapter V.

3.2.4 <u>AVM Labor Costs</u>. The AVM cost estimates described in the preceding section include all labor for programming, installation, calibration and maintenance. Computer support will be provided by a closed loop minicomputer which will not require a dedicated operator. Off-line analyses of management information and related computer operations are assumed to be an extension of present data processing programs rather than unique costs attributable to AVM. Vehicle dispatch consoles are designed to support up to 250 vehicles, similar to the workload of present base case dispatchers. Vehicle operators will perform at the same skill and pay levels with or without AVM.

There are two potential labor expenses which may not be accounted for in these assumptions. The first is the non-productive time devoted to AVM start-up training, which may require up to four hours for each vehicle operator (this would be a one-time expense since refresher and new personnel training would be included in regular training programs). The second potential expense is in increased skill and consequent salary levels for dispatchers. For example, the St. Louis Police Department is installing a city-wide AVM system and replacing police cadet dispatchers with lieutenants. Neither of these expenses are reflected in the base case data. The first is omitted, because the training expenses are considered speculative, and the second is omitted because the use of senior personnel as dispatchers may reflect a unique policy choice by one type of fleet in one city. However, the model has the capability to add additional labor, equipment and installation costs. Test runs indicate that costs covering the four hour startup training have a negligible impact on the bus results, though a shift to lieutenant dispatchers would have a discernible impact on the police results. (Specifically, the inclusion of these factors would increase system costs and decrease benefit-cost ratios by 2.5% for the bus and by 10% for the police.) Future cost projections and field tests must address these topics more clearly and, in the meantime,

police planners in particular should be sensitive to the area of dispatcher requirements.

3.2.5 <u>Multiple User Cost Sharing</u>. Shared AVM systems have been expected to lower costs for participating users and, as indicated above, the TSC model provides a mechanism for testing this hypothesis. In order to do this, a standard or rule to apportion common costs among users was adopted. This standard prorates basic data processing and communications costs according to the number of vehicles and then distributes wayside equipment costs according to both the number of vehicles and the square miles (or route miles, if appropriate) in individual service areas. Within any given area, wayside costs are divided in direct proportion to the size of each fleet which serves that area. When a fleet operates in two or more areas -- as the bus fleet does in the base case --its vehicles are assumed to be uniformly distributed and directly proportioned to the two areas served. (The model can alternately calculate proportionate costs on the basis of route miles instead of areas.) When an operator deploys the only instrumented vehicles in any area -- as the bus does outside the core in the base case -- he bears all of the wayside costs attributable to that area. As a result, all vehicles and all operators are treated

equally; there is no allowance for differences in benefits, ability to pay, or any other such criteria.

All participants in a shared AVM system must install and use the same type of location system. It is possible that the location system which was the lowest cost choice for an independent AVM user would not be the lowest cost choice for the total combined fleet. When this happens the share of multiple user costs may be little less than the price of an independent dedicated system. It is also conceivable that one user could require much greater accuracy and thus more expensive equipment than the other users; such a situation would probably preclude participation in a shared system.

3.2.6 Limitations of the Cost Results. The method of assigning and apportioning costs used in this study is adequate for comparing urban areas of varying sizes and making an estimate of the benefit/cost ratio for a go/no go decision, but it is insufficient to determine the exact cost of any unique application. Any decision on actual AVM implementations must give detailed consideration to factors omitted in the model, such as the exact shape of the service area and possible overlap of route miles, and must insure that assumptions and cost factors of the model have been tailored to the specific features of the system at hand.

3.3 AVM Benefit Evaluation

3.3.1 Location System Performance. The UMTA/TSC AVM system specification requires location accuracy of closer than 300 feet and time accuracy of better than 15 seconds. All contractors claim to have achieved these standards. Since there has been no competitive evaluation of location system performance, the benefit-cost analysis assumes that each class of location system meets these requirements and thus can provide equivalent benefits. As a result, only one benefit total is calculated for each deployment scneario. A comparison is then made between this benefit total and the total cost of the least expensive location system for that deployment. Since the assumption of equal performance accuracy may be questioned, the model has the option to compare benefits against any location system cost total. Chapter V presents the full range of cost and benefit combinations for each deployment scenario.

3.3.2 Derivation and Meaning of Benefit/Cost Ratios. All costs and dollar benefits are expressed in constant 1975 dollars in order to eliminate the impact of inflation. These constant dollars are then converted to present value dollars by discounting at ten percent annually over the ten year life of the AVM system. This is done for all comparisons and evaluations since the present value

technique yields a unit of measure which reflects both the dollar magnitude and the time value of money by giving greater emphasis (at ten percent per year) to cost and benefits realized early in the project than to those realized at later times.

Final results are presented as benefit-cost ratios (B/C), which are present value benefits divided by present value costs. A benefit-cost ratio greater than 1.0 indicates that an alternative is a productive investment, returning dollar benefits which exceed system costs. A benefit-cost ratio of less than 1.0 indicates that system costs exceed dollar-benefits -- that is, that the alternative under consideration does not pay its way in terms of dollar benefits.

3.3.3 Service and Management Improvements. Benefit-cost ratios reflect only those factors which have been expressed in monetary terms. One significant AVM benefit--the set of security benefits--has not been monetized because two factors combine to produce highly speculative savings figures. These factors are low confidence in the dollar values which may be assigned to a particular benefit and unusual difficulty in demonstrating a causal connection

between the benefit and AVM. Security benefits are discussed in Chapter VII.

It is important to note that a decision against monetizing a benefit does not imply insignificance. On the contrary, important benefits are discussed in Chapter VII -- benefits which decision-makers may conclude are sufficient to justify proceeding with an investment which, in dollar terms alone, appears to be marginal or non-productive.

3.3.4 Capture of Dollar Benefits. Most AVM benefits appear in the area of fleet efficiency and productivity. Efficiency and productivity improvements, whether from AVM or any other source, require managers and policy makers to choose a strategy to exploit those improvements. This choice may be made explicitly or implicitly, but it cannot be avoided. The almost infinite range of exploitation possibilities can be summarized best as a continuum (illustrated below) between two polar strategies: either plow back the added productivity to increase the level of service produced by the present number of vehicles and personnel; or capture the added productivity by reducing the fleet and staff size to the minimum required to maintain the current level of service.

INCREASED EFFICIENCY. . .

REQUIRES A CHOICE BY
LOCAL POLICY-MAKERS. . .

IMPROVED SERVICE YIELDING PUBLIC BENEFITS	OR	CONSTANT SERVICE YIELDING OPERATING ECONOMIES

Attention to the choice and design of management's exploitation strategy is crucial for analysts since it defines the benefits which must be measured. In this study, a pure strategy of capturing benefits by cost reduction is assumed. This represents a valid goal for transit and public safety managers; it defines clearly the resources freed by AVM technology; it minimizes the danger of double-counting benefits; and it avoids speculative benefit methodology, such as valuations of patron wait and travel time. And in the end, this choice of strategy remains an analytic artifice, one which leaves to each individual community the real philosophical and managerial questions of using AVM improvements to reduce budgets or to increase public service.

3.3.5 <u>Estimating the Range of Dollar Benefits</u>. The ideal estimate of AVM benefits would be succinct and confident--a single figure summarizing a mass of data. Unfortunately,

the trade-off between precision and confidence in the projection of AVM impacts is such that the study does not present single "most likely" benefit estimates. It became clear in our analysis that many uncontrollable variables and considerable uncertainty lie between this study and the real-world impacts of a large scale AVM system. These obscuring elements range from economic, social, and political trends, to issues of management choices and effectiveness. In order to reflect these uncertainties and to highlight the sensitivity of AVM payoffs to them, the study presents sets of high and low benefit estimates which are rooted as much as possible in empirical data. In the low cases the estimates represent conservative applications of AVM experience, often understating demonstrated achievements. In the high cases the estimates are optimistic yet reasonable projections based mostly on accomplishments. Although the low estimates entail less risk, they are no more "probable" than the high estimates. Since significant uncertainty exists, it is more useful to mark the high and low limits of that uncertainty -- even if the gap is uncomfortably large -- rather than cover up the uncertainty with the spurious precision implied by a single best estimate.

3.3.6 Sensitivities. The TSC benefit-cost study of AVM is a complex interplay of many assumptions, and it highlights the impact of key assumptions by means of sensitivity analysis. This demonstrates the magnitude of change in the study results given specific changes in inputs and facilitates a generalized application of the results to other urban areas or AVM deployments. Since AVM location system costs vary in relation to type of fleet, fleet size, and operating area, the model is used to search for changes in the low cost location system; this is discussed in Chapter IV. Resulting benefit-cost ratios are also examined for the different fleets in relation to density, urban size, operational characteristics, and AVM impacts. Density is varied by adjusting fleet size and operating area as single factors. Urban size reflects the total mix of area, fleet size, and operating characteristics. Key operating characteristics include the proportion of a bus fleet operating on short headways, the amount of layover in the system, the extent of the manual data collection effort, the percentage of non-revenue mileage in a taxi fleet, and the percentage of preventive patroling performed by police cruisers. AVM impacts focus on operating efficiencies -- that is, changes in the key operating characteristics. This information is presented in Chapter VI.

IV. AVM SYSTEM COSTS

Chapter IV is a discussion of AVM life cycle system costs. It begins with a brief description of the cost calculation method, then presents the costs of the four base case deployment scenarios for bus, police and taxis operating independent AVM systems, and for all three sharing a multiple user AVM system. After a breakdown of the cost shares for the multiple user system, the chapter concludes by reviewing the impacts of fleet size, fleet type and operating area on the location system cost rankings.

4.1 Development of System Costs

As indicated in Chapter III, the AVM costs displayed in this study are an extrapolation of cost factors distilled from eight contract proposals. Some cost factors are fixed and others vary according to fleet size, route miles, or square miles. The factors reflect the on-vehicle, wayside and central equipment costs appropriate to each of the four generic location systems. On-vehicle costs vary only with the size of the fleet, and wayside costs vary only with the dimensions and structure of the operating area. Central equipment costs have fixed minimum computer and communication costs tied to each type of location system, regardless of system size, plus variable computer and

communication costs which grow along with the size of the service area and/or the number of vehicles.

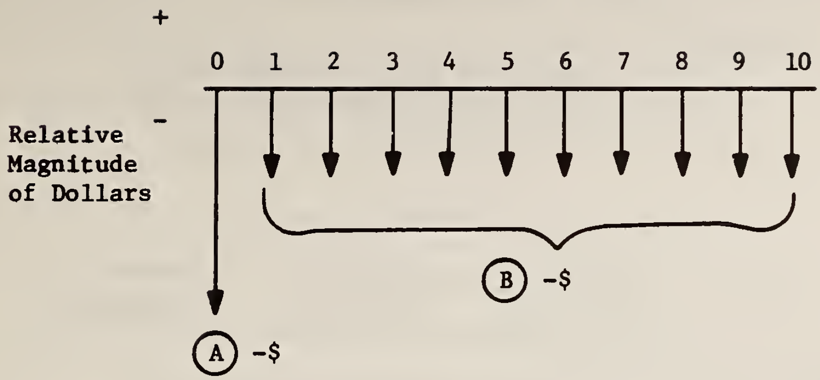
The sum of the on-vehicle, wayside and central equipment costs is the total capital cost of the system. With minor exceptions, annual maintenance costs are estimated at ten percent of the capital cost of each type of equipment. These annual costs, which are expressed in constant 1975 dollars, are converted to a single present value amount for maintenance and this figure is added to the capital costs, producing a total life cycle cost expressed in present value dollars. This is illustrated in Figure IV-1. A more detailed review of the cost calculations (cost uncertainties were explained on page 3-10) is in Appendix B and the location system cost factors may be found in Appendix A.

4.2 AVM Costs for the Bus Alone

The base case bus fleet consists of 2,400 vehicles serving 3,825 route miles within a service area of 5,000 square miles. Since neither police nor taxis will be sharing the AVM system in this deployment, the 475 square mile core area in which they operate requires no special attention.

Table IV-1 presents the life cycle AVM system costs for the base case bus fleet operating alone. Notice that the sharp

AVM LIFE CYCLE IN YEARS



A $ = Initial Capital Costs of:

- On Vehicle Equipment
- Wayside Equipment
- Central Equipment

B $ = Annual Maintenance Costs
(10% of Appropriate Capital Costs)

$$\text{TOTAL (PV) Costs} = A_{1} + \text{PV } B_{1 \rightarrow 10}$$

FIGURE IV-1

AVM LIFE CYCLE COSTS

TABLE IV-1

AVM LIFE CYCLE SYSTEM COSTS
FOR A SINGLE-USER BUS FLEET

(Present Value, $000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	7,146	2,826	3,906	9,762
Wayside Equipment	1,318	475	1,193	2,396
Central Equipment	838	575	302	1,425
Total Capital Costs	9,302	3,876	5,401	13,584
Cost Uncertainty	±20%	±5%	±18%	±6.5%
Total Maintenance Costs	5,716	2,511	3,448	8,053
Total System Costs	15,018	6,387	8,849	21,637

[1]Present value calculated at ten percent discount rate.

signpost and dead reckoning location systems are two to three times more expensive than the broad signpost and radio frequency techniques. Both of the highest cost systems possess sophisticated and expensive on-vehicle components, which explains much of their total cost disadvantage.

Displaying the least expensive central computer and communication costs, the radio frequency technique is much more economical than the preceding location systems, yet it still suffers a 28% disadvantage when compared to the broad signpost. The low cost of the latter is explained by relatively inexpensive on-vehicle equipment and the ability to place wayside instruments only along the bus routes.

A central assumption of this analysis is that all location systems meet the same performance standards. If this assumption is abandoned, as is possible after field tests are completed, sharp signpost and dead reckoning -- and even radio frequency -- would have to exhibit substantial fixed route performance advantages to be preferable to broad signpost at current price estimates.

4.3 AVM Costs for the Police Alone

The base case police fleet consists of 1,330 cruisers providing service in a 475 square mile area. The AVM system

must cover this entire operating area, not just a lattice work of routes on major thoroughfares as in the bus alone scenario. The impact of the total area requirement is clear in Table IV-2, which presents the single user police costs. Both signpost systems are at a disadvantage due to the need for extensive wayside equipment deployments. Dead reckoning, which had been the highest cost option for the bus alone, is now some two million dollars below sharp signpost for this random user application. Radio frequency is now less expensive by over one million dollars compared to the broad signpost system. Despite the impact of area coverage, broad signpost remains substantially less expensive than dead reckoning. Radio frequency is the least expensive police only system by a margin of 21%.

4.4 AVM Costs for the Taxi Alone

The base case assumes that 800 taxis operate in a 475 square mile area and are supported by a single dispatch system. The AVM coverage requirements for this area are identical to the police, and the location system costs exhibit the same rank order for both operators. However, the smaller size of the taxi fleet heightens the difference already noted between the bus and the police. Radio frequency reflects a 34% cost advantage over broad signpost because the smaller taxi fleet deemphasizes radio frequency's higher on-vehicle

TABLE IV-2

AVM LIFE CYCLE SYSTEM COSTS
FOR A SINGLE USER POLICE FLEET
(Present Value, $000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	4,323	1,530	2,128	5,320
Wayside Equipment	2,852	1,325	238	254
Central Equipment	586	415	214	978
Total Capital Costs	7,760	3,269	2,580	6,552
Cost Uncertainty	±20%	±5%	±18%	±6.5%
Total Maintenance Costs	4,794	2,037	1,614	4,002
Total System Costs	12,555	5,306	4,193	10,553

[1] Present value calculated at ten percent discount rate.

costs. And further, due to the total number of signposts needed to meet random user areawide coverage requirements, there are no compensating reductions in broad signpost's higher wayside costs. A similar relationship between dead reckoning and sharp signpost results in four relatively evenly spaced costs. This is in sharp contrast to the bus and police deployments, which produced marked gaps between the two highest and two lowest cost location systems. Taxi cost data is presented in Table IV-3.

TABLE IV-3

AVM LIFE CYCLE SYSTEM COSTS
FOR A SINGLE USER TAXI FLEET
(Present Value, $000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	2,600	920	1,280	3,200
Wayside Equipment	2,846	1,325	237	253
Central Equipment	460	335	186	720
Total Capital Costs	5,906	2,580	1,703	4,173
Cost Uncertainty	±20%	±5%	±18%	±6.5%
Total Maintenance Costs	3,655	1,608	1,069	2,535
Total System Costs	9,561	4,187	2,772	6,708

[1]Present value calculated at ten percent discount rate.

4.5 AVM Costs for the Multiple User Fleet

The fourth deployment scenario assumes that the bus, police and taxi fleets are served jointly by a single AVM system. The operating area for this mixed fleet, pictured earlier in Figure III-3, consists of two concentric areas. The 475 square mile inner core area is served by police, taxi and bus, while the remaining 4,525 square miles in the outer ring is served only by the bus. The 3,825 total bus route miles are divided with 2,647 route miles (69%) in the outer ring and 1,178 route miles (31%) in the inner core. (In the absence of more appealing logic this assumption was based on the proportionate relationship between the radii of the two areas.)

The structure of the service area requires that the AVM system combine total area coverage within the 475 square mile core area with a skeletal route structure outside the core. Since it is assumed that the same location system must be used throughout the service area, the cost ranking becomes a contest between the advantages which broad signpost displayed in the bus-only system and those that radio frequency displayed in the two random route systems. As Table IV-4 illustrates, broad signpost enjoys a 10% cost advantage over radio frequency. Lower unit costs for on-vehicle equipment enable broad signpost to overcome

disadvantages in wayside and central equipment. Notice, too that a large gap has reappeared between the two lowest cost and the two highest cost location systems.

TABLE IV-4

AVM LIFE CYCLE SYSTEM COSTS FOR A MULTIPLE-USER SYSTEM
(Present Value, \$000)[1]

	Sharp Signpost	Broad Signpost	Radio Frequency	Dead Reckoning
Capital Costs				
On-Vehicle Equipment	14,069	5,276	7,314	18,282
Wayside Equipment	3,847	1,689	1,096	2,270
Central Equipment	1,468	975	410	2,627
Total Capital Costs	19,384	7,940	8,820	23,179
Cost Uncertainty	±20%	±5%	±18%	±6.5%
Total Maintenance Costs	12,205	5,099	5,623	14,408
Total System Costs	31,589	13,039	14,443	37,587

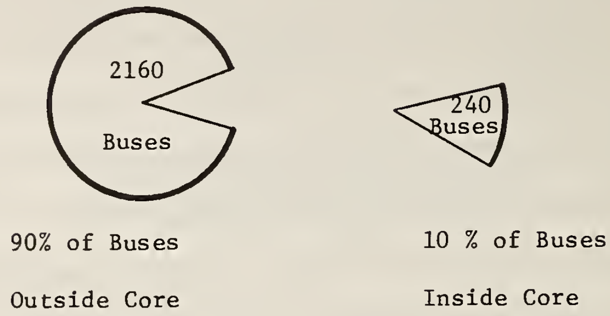
[1]Present value calculated at ten percent discount rate.

4.6 Cost Shares for the Multiple User System

Two cost elements are shared in a multiple user system. The first, fixed central computer and communication costs, are basic charges which are not considered sensitive to differences in service areas. Because of this, these costs are divided among users in direct proportion to the total number of vehicles in each participating fleet. The second element, wayside equipment costs, is more complicated because it is directly related to operating areas.

As indicated in Chapter III, common user wayside costs are apportioned in relation to the number of vehicles in areas used by two or more instrumented fleets. Thus the bus bears all costs associated with the outer ring, where it operates alone, but shares costs associated with the core. In order to determine the shares within the core it is necessary to apportion the bus fleet between the outer ring and the core. This is done in direct relation to the number of square miles in both areas, 90% in the outer ring and 10% in the core; the result, illustrated in Figure IV-2, attributes 240 buses to the core.

(1) First, Distribute Buses Between Areas:



(2) Then Distribute Core Costs Among 2370 Users:

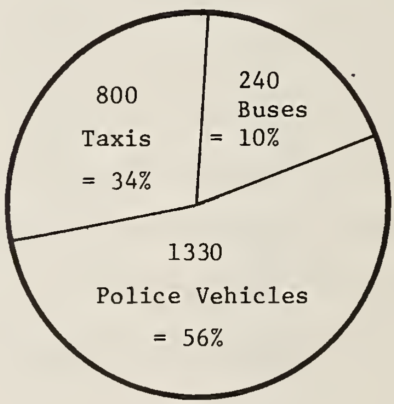


FIGURE IV-2

<u>CALCULATION OF MULTIPLE USER COST SHARES</u>

Core wayside costs are divided in proportion to fleet size, with 56% to the police (1330 vehicles), 34% to the taxi (800 vehicles), and 10% to the bus (240 vehicles). Each user's total share of the lowest cost multiple user system is shown on Table IV-5.

TABLE IV-5

COST SHARES FOR THE LOW-COST MULTIPLE USER SYSTEM, BROAD SIGNPOST LOCATION SYSTEM

(Present Value, $000)[1]

	Bus	Police	Taxi	Total System
Capital Costs				
On-Vehicle Equipment	2,826	1,530	920	5,276
Wayside Equipment	496	745	448	1,689
Central Equipment	493	291	191	975
Total Capital Costs	3,815	2,566	1,559	7,940
Total Maintenance Costs	2,546	1,588	965	5,099
Total System Cost	6,361	4,154	2,524	13,039
Percentage Shares	49%	32%	19%	100%

[1]Present value calculated at ten percent discount rate.

Table IV-6 compares cost shares in the low cost multiple user system with low cost individual AVM systems. Although one would expect shared infrastructure costs to produce meaningful savings, this is not the case. Total AVM multiple user costs savings -- 0.5% for the bus, 1% for the police, and 9.1% for the taxi--do not appear to justify the additional management time and coordination which a shared system would demand.

The surprisingly small advantage of a shared system is due to two factors. First, the shared system elements represent a relatively small part of the total costs. In the shared broad signpost system only 24% of total costs are associated with the purchase and maintenance of shared infrastructure costs. Second, the decision to participate in a shared system--that is, the desire to parcel out part of the common costs--addresses the lowest cost system which, in this case, differs from each participant's optimum individual system, and thus dilutes their associated cost savings.
Specifically, the bus fleet must absorb part of the costs for instrumenting the entire 475 square mile core instead of just fixed route miles; and the police and taxi fleets must buy into a location system which is not their optimum low cost choice. Table IV-6 shows clearly that the benefit of

TABLE IV-6

COMPARISON OF SINGLE AND MULTIPLE USER COSTS FOR THE LOW COST LOCATION SYSTEM

(Present Value, $000,000)[1]

	Low Cost Individual AVM	Share of Low Cost Multiple User AVM	Multiple User Savings
Bus	6.39*	6.36*	0.5%
Police	4.19**	4.15*	1.0%
Taxi	2.77**	2.52*	9.1%
TOTAL COST	13.35	13.03*	2.4%

*Broad Signpost

**Radio Frequency

[1] Present value calculated at ten percent discount rate.

sharing 24% of system costs barely outweighs the negative impact inherent in suboptimal technology choices.

There are, however, deployment scenarios which would extract more advantage from a multiple user AVM. The fleet structure which would draw the greatest advantage appears to be a shared random route or blanket coverage system with minimal variation in service area boundaries. This structure increases the likelihood that the same location system would be low cost in all possible combinations of users, and it increases the proportion of wayside costs eligible for sharing. A test run of a multiple user system serving only police and taxi (base case fleets) resulted in multiple user cost reductions of 6% for the police and 14% for the taxi.

4.7 Sensitivity of Location System Cost Rankings

The preceding section partially illuminated the interaction between fleet sizes, operating areas, and potential advantages of multiple user cost sharing. That interaction is rooted in the impact of fleet size and operating area on system costs, and this section examines more closely the

relationship between those variables and the cost rankings of the four generic location systems. As a reference, Table IV-7 summarizes the total costs of all base case fleet and location system combinations.

TABLE IV-7

TOTAL SYSTEM COST ESIMATES

(Present Value, $000,000)[1]

	Deployment Scenario			
	Bus Only	Police Only	Taxi Only	Multiple User
Sharp Signpost	15.0	12.6	9.6	31.6
Broad Signpost	6.4*	5.3	4.2	13.0*
Radio Frequency	8.8	4.2*	2.8*	14.4
Dead Reckoning	21.6	10.6	6.7	37.6

*Lowest cost system for each deployment scenario.

[1]Present value calculated at ten percent discount rate.

Cost sensitivity analysis begins with the benefit-cost model. A minimum of four variations were run for each set of parameters which are addressed below. The data from the model were analyzed with regression techniques and extended on charts for visual interpretation. The resulting cost curves have the appearance of straight lines primarily because all costs are based on estimates for a 1,000 vehicle purchase; they do not reflect economies of scale beyond that point. In addition, several cost elements are constant in each sensitivity case as they are unaffected by the test variable, just as wayside costs are unaffected by changing the fleet size.

Location system relative costs appear to be insensitive to fixed route fleet size. As Figure IV-3 illustrates, varying bus fleet size <u>within the constraints of the base case</u> produced no change in the relative rank of location system costs. Broad signpost holds a clear cost advantage which increases monotonically with fleet size.

Location system cost rankings do change in response to random route fleet size, but only when the fleet is extended to very small or very large numbers of vehicles relative to the operating area. Figure IV-4 shows the relatively high initial wayside costs imposed on both signpost systems by

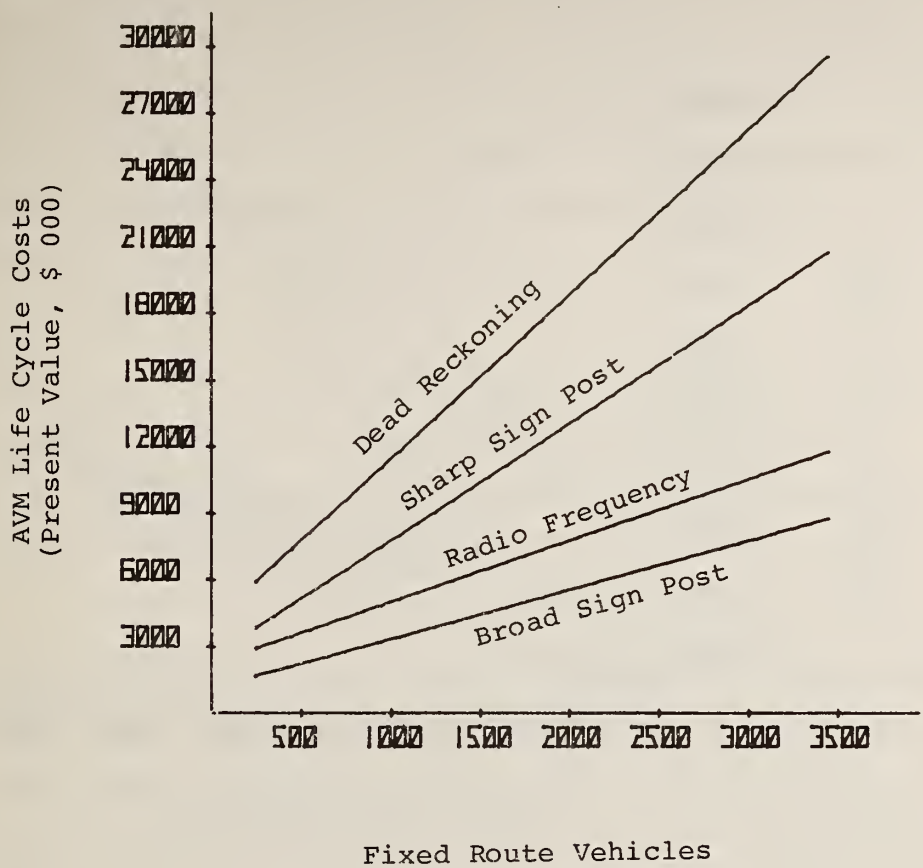


FIGURE IV-3 LOCATION SYSTEM COST AS A FUNCTION OF FIXED ROUTE FLEET SIZE*

*Within Constraints of Base Case Except for Fleet Size

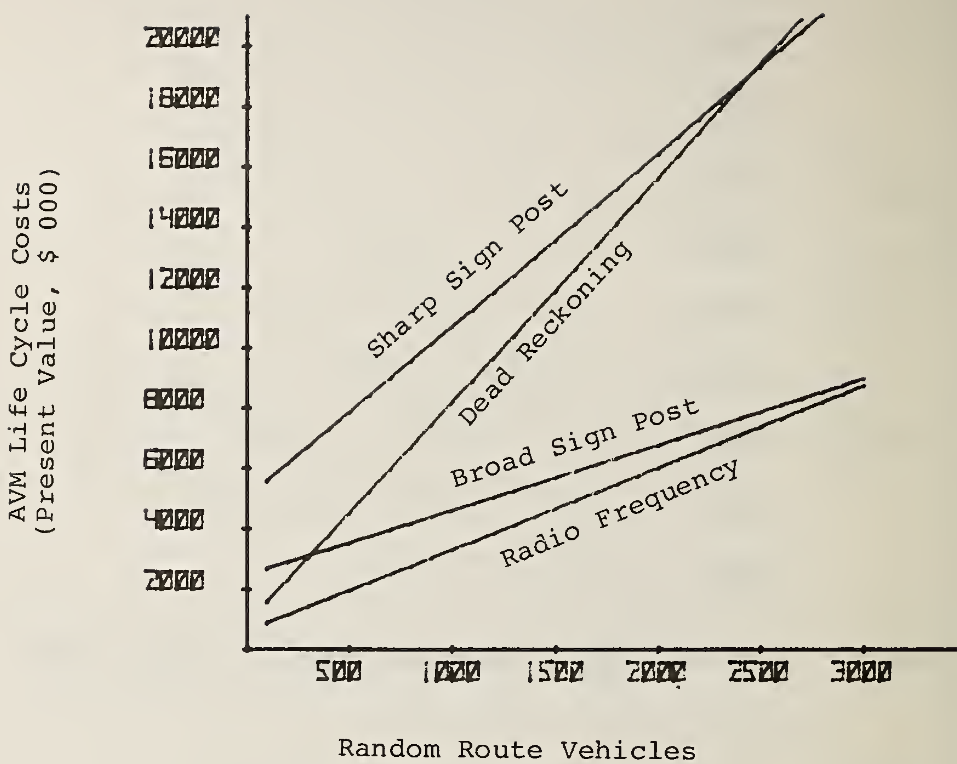


FIGURE IV-4

LOCATION SYSTEM COST AS A FUNCTION OF RANDOM ROUTE FLEET SIZE*

*Within Constraints of Base Case Except for Fleet Size.

the dimensions of the area even when there are no vehicles. The slope of the cost lines show the variation in per-vehicle costs of each system. Broad signpost becomes competitive with radio frequency at the point where the higher per-vehicle ccsts of radio frequency outweigh the higher wayside costs of broad signpost--at about 3,000 vehicles in a 475 square mile area.

Higher per unit costs and coverage requirements of dead-reckoning wayside equipment changes the competitive relationship between dead reckoning and sharp signpost systems at about 2,500 vehicles.

Sensitivity of location system cost rankings for multiple user fleets was tested by varying the total number of random route vehicles which were added to the base case fleet. These random route vehicles were restricted to the 475 square mile core area while the 2,400 buses operated throughout the 5,000 square mile service area. Figure IV-5 presents the total system costs (it does not address cost shares between users). The resulting curves are similar to those of the fixed route fleet in that location systems are continuously in the same rank order. However, in this case there is a marked gap between the two highest and two lowest

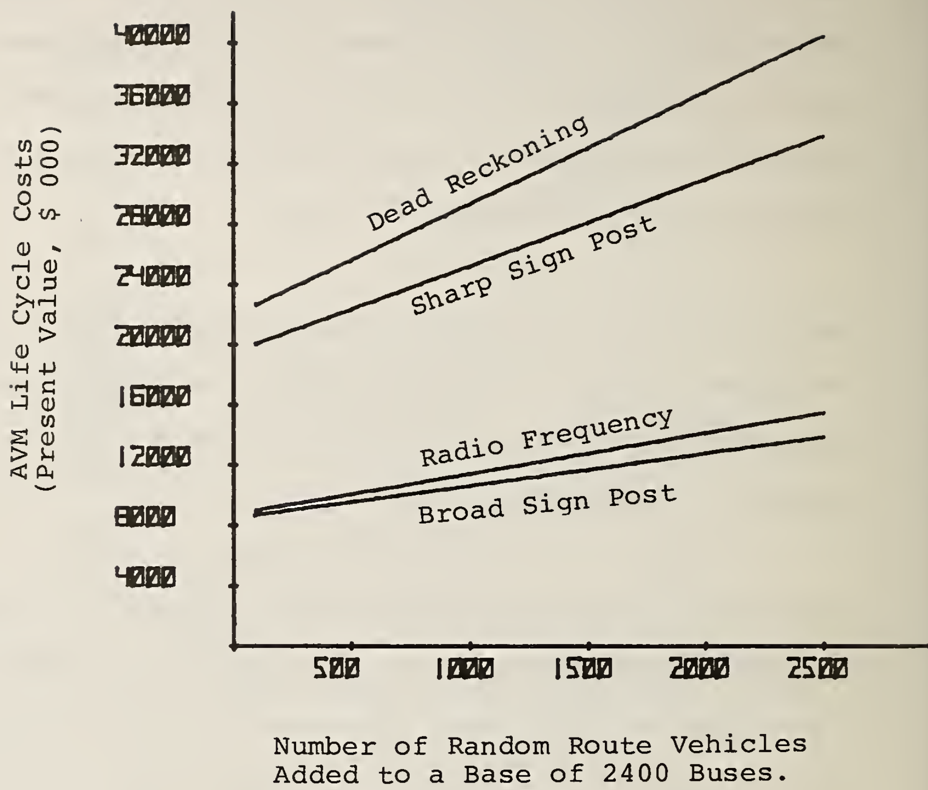


FIGURE IV-5

LOCATION SYSTEM COST AS A FUNCTION
OF MULTIPLE USER FLEET SIZE*

*Within Constraints of
Base Case Except for
Fleet Size.

cost location systems and a very small difference between broad signpost and radio frequency costs.

The final cost sensitivity test looks at the impact of operating area on random route cost rankings. For a fleet of 1,000 vehicles we see in Figure IV-6 that radio frequency has an increasing cost advantage over broad signpost as the operating area increases beyond about 125 square miles. The crossover between broad signpost and radio frequency at 125 square miles is analagous to their crossover beyond 3,000 vehicles in Figure IV-4, which varied random route fleet size in a fixed area. In general terms, broad signpost costs improve relative to radio frequency costs as the vehicle density increases.

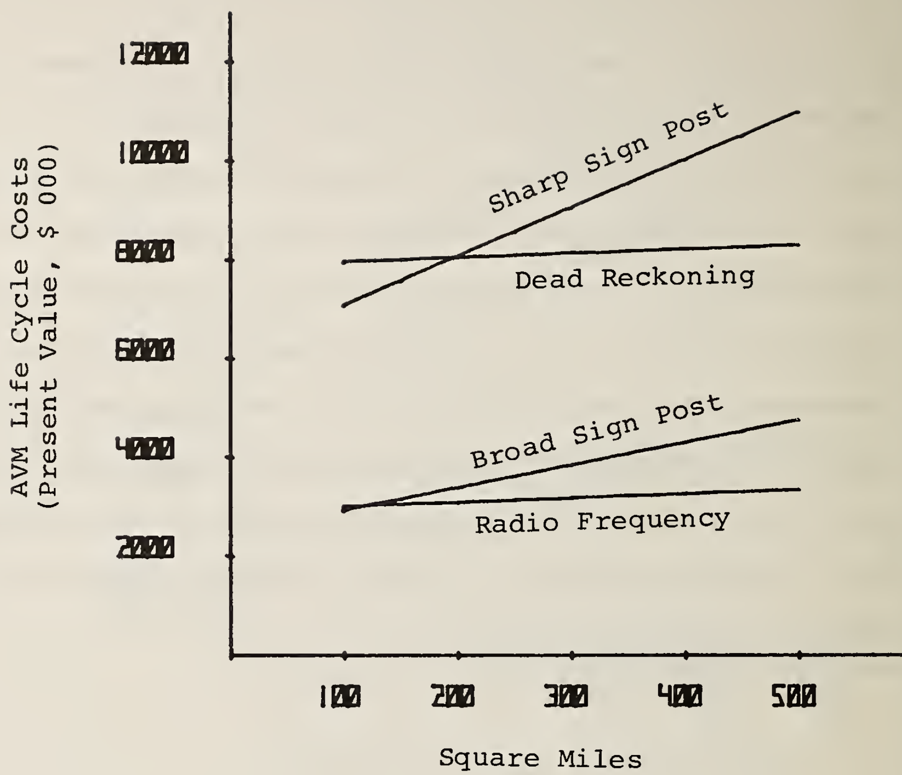


FIGURE IV-6

LOCATION SYSTEM COST AS A FUNCTION OF OPERATING AREA*

*For 1,000 Random Route Vehicles Within Constraints of Base Case.

V. AVM SYSTEM BENEFITS

This chapter discusses the impact of AVM on bus, police, and taxi operations; the dollar value of those impacts; and the relationship between system costs and benefits. Section 5.1 explains the methods used to sum dollar savings for all users. The next three sections focus on the bus, police, and taxi fleets, and the final sections review the results for the combined multiple user fleet. Data values used in the benefit calculations are listed in Appendix A.

5.1 The Measurement of Benefits

Most AVM benefits center around fleet productivity and result in an estimate of the number of vehicles which may be saved without affecting service. In these cases the unneeded vehicles are the catalysts which produce capital, operating, and payroll savings. All savings quantified in this study, regardless of source, fall into one of these three categories: vehicle capital costs, vehicle operating and maintenance (O&M) costs, and personnel costs.

5.1.1 Vehicle Capital Costs. Vehicle capital savings begin with a projection of the impact of AVM on fleet size and yield an estimate of the number of vehicles to be saved. These savings begin to be realized at the end of the first

year of AVM operation. Savings are realized by avoiding normal replacement purchases, not by selling excess vehicles, which means savings may not be realized any faster than the fleet deterioration or attrition rate.

Fleet attrition is determined by dividing the average vehicle life into the fleet size. Thus a bus fleet with 1,500 vehicles and a ten year average vehicle life would replace 150 buses each year. If AVM saved 100 vehicles the fleet would purchase only 50 buses at the end of the first year, realizing cost savings of the present value of the net cost of 100 buses, one year in the future. Example 1 in Figure V-1 illustrates this process.

Police cruisers and taxis have relatively short lifespans, requiring each vehicle in the fleet to be replaced several times during the AVM system life of ten years. A fleet of 1,500 police cruisers with an average life of three years would replace 500 cars each year. If AVM saved 100 vehicles in this fleet, the police would purchase only 400 vehicles at the end of year one, saving the cost of 100 cruisers at that point. In addition, they would save the cost of those cruisers again at the end of the fourth and seventh years of the AVM life cycle -- the points at which on average they would have had to replace the cruisers again had it not been

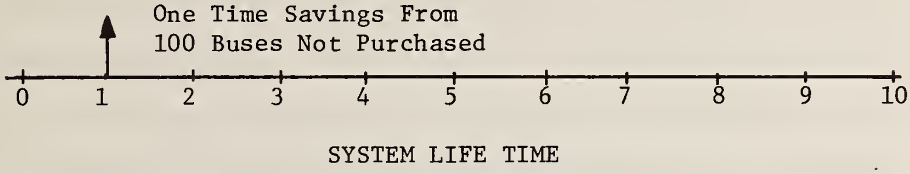
for AVM. The total capital saving is the present value of the savings at years one, four, and seven. Example 2 in Figure V-1 depicts this process.

<u>Example 1</u>

1500 Bus Fleet

10 Years Bus Life

100 Buses Can be Saved



<u>Example 2</u>

1500 Police Fleet

3 Year Car Life

100 Vehicles Can be Saved

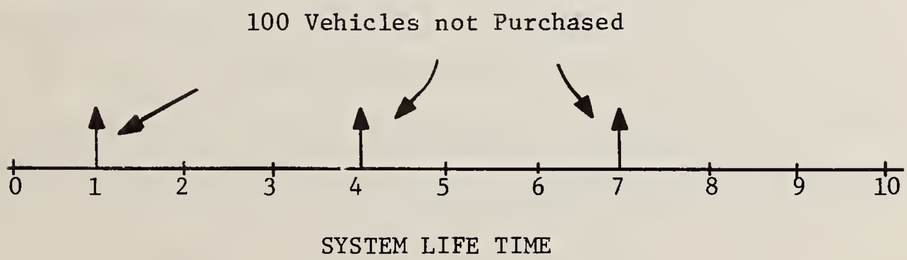
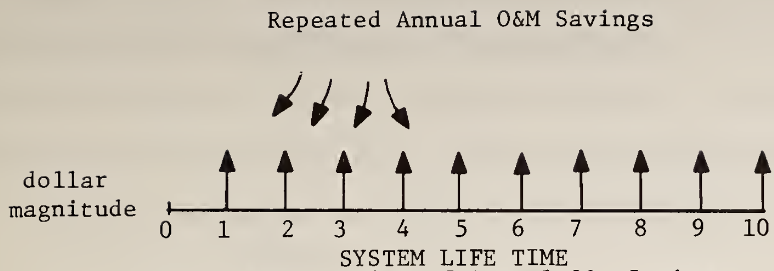


FIGURE V-1

<u>CALCULATION OF VEHICLE CAPITAL SAVINGS</u>

5.1.2 Vehicle O&M Costs. Reductions in fleet size are generally associated with reductions in vehicle operating costs. A substantial portion of operating costs are tied directly to vehicle mileage, but there are also cost elements inherent in the ownership of a vehicle which do not vary with mileage. The first category includes costs such as fuel, tires, and most periodic maintenance; the second category includes insurance and periodic maintenance performed according to the calendar. While one category of AVM bus savings is limited to fixed O&M reductions, the remainder of the bus savings and all police and taxi savings reflect both fixed and variable O&M.

First, the annual dollar amount of O&M per vehicle which is incurred by the set of vehicles being saved must be determined. This will be the 1975 dollar equivalent of either the fixed O&M alone or the total O&M. When multiplied by the number of vehicles which are saved, this produces a total recurring annual benefit. The total O&M savings for each set of vehicles is the present value of the repeated annual savings, as illustrated in Figure V-2.



Total Present Value of Annual O&M Savings...

$$= \sum_{1}^{10} \text{PV of Each Annual Saving}$$

FIGURE V-2

CALCULATION OF OPERATING AND MAINTENANCE SAVINGS

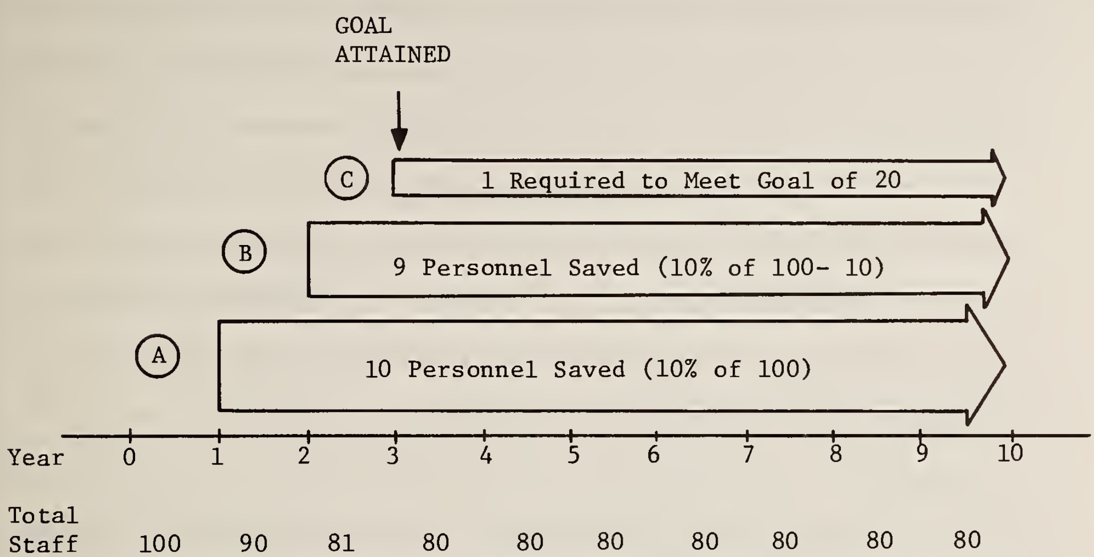
5.1.3 Personnel Costs. Staff reductions produce savings in salary, benefits, and overhead. Salaries vary in terms of skill levels, seniority, overtime, and industry practice; some jobs are paid almost exclusively by commission. Benefits include employer contributions to insurance and pension programs, social security, and workmen's compensation. Overhead consists of administrative and supervisory support costs. Since each job category addressed in this study has a unique mix of cost elements, the model calculates the average 1975 dollar value of individual compensation which fits every category.

The number of positions which can be saved due to AVM reflects the characteristics of each particular efficiency improvement. In some cases the saving is tied directly to the number of vehicles saved. In other cases it is usually determined according to changes in operating hours.

Since a variety of legal, labor, and community practices limit management's freedom of action in realizing staff reductions, it is likely that staff savings made possible by AVM would not be achieved immediately. Such savings usually are realized over a period of years through attrition, and it is possible that the total reduction target may not be reached by the end of the AVM's ten year life cycle.

The model applies the best available attrition rate to the work force in question and determines the number of positions which will be vacated in the first year. Next, it calculates the 1975 dollar value of the first year's attrition, and then, since avoided salaries are a recurring benefit, the model determines the present value of this savings over the AVM life cycle. This value is stored, the staff size is reduced, and the model moves to year two where it applies the attrition rate to the reduced staff and calculates the present value of that year's attrition. This is repeated until the staff reduction goal is achieved or

the ten year AVM life cycle is exhausted. Figure V-3 is a simplified illustration of this calculation.



INITIAL STAFF = 100

TARGET REDUCTION OF 20

ATTRITION RATE = 10%

A = 9 years of savings of annual payroll for 10 people

B = 8 years of savings of annual payroll for 9 people

C = 7 years of savings of annual payroll for 1 person

FIGURE V-3

ILLUSTRATION OF PERSONNEL SAVINGS THROUGH ATTRITION

5.2 AVM Benefits for the Bus

AVM can reduce bus operating costs in three significant ways. First, it can reduce the requirement for manual data collection by providing an interface for transmitting optional passenger counter data. Second, AVM can reduce non-productive bus layover time when exact position location information is used to improve schedule adherence. Finally, AVM can free buses on some routes by enabling schedulers to lengthen headways without increasing the average wait time perceived by passengers. This section discusses each of these impacts, then presents the overall bus benefits and conclusions.

5.2.1 Data Collection Benefits. Bus managers need data on actual run times and on passenger utilization of their service, stop by stop, in order to insure that schedules are realistic and meet the needs of the community. Accurate run times in schedules encourage improved public acceptance and good labor relations. Good measures of passenger demand insure that some routes are not over-served nor others inadequately served. In addition, some metropolitan areas use measures of demand to apportion community support of operating deficits.

Many properties employ checkers to collect this kind of information. Checkers, who earn an average $15,800 in the base case, ride buses and record times and numbers of passengers by stop. The location reporting capability of AVM provides the time and place aspects of this manually gathered information, and the addition of a mechanical passenger counter (costing $550) to a bus's AVM digital data link makes it possible to eliminate the manual efforts of counting passengers. (Data reduction and manipulation is assumed to be roughly equivalent in both techniques.)

The base case bus fleet employs 60 checkers. When AVM is implemented, 120 of 2400 buses are equipped with passenger counters. These buses can be shifted from route to route to gather data, just as are the checkers. As a result of this capability, it is assumed that the base case fleet can reduce its requirement for manual checkers by two-thirds without reducing the quality of data which it collects. This may be conservative since; (a) there are two counter-equipped buses for each initial checker; (b) the buses do not have shift and overtime restrictions; and (c) a staff of twenty people is still maintained to supplement the automated capability. However, this allows a cushion for any mechanical difficulty that may arise with the counters and permits the operator to retain flexibility.

AVM permits the base case to save 40 checker positions, and the incumbents may be released or given other duties within the property. In the first case, 40 personnel must be reduced through attrition, since it is assumed that layoffs are not acceptable. This situation constitutes the low estimate of the data collection benefits, and the forty positions are vacated at an attrition rate of ten percent applied initially to the total force of 60 checkers and annually thereafter to the subsequently reduced staff. As a result, it takes ten years to reach the goal of forty position savings. When the checkers are given other duties they can be absorbed much more quickly and, in the high estimate of the data collection benefit, the forty positions are vacated by applying the ten percent attrition rate to the total transit property administrative work force. This reduces the checker force to the desired strength of 20 people within a year.

The low case data collection benefit yields present value savings of $3,795,600, which covers 59% of the present value costs of implementing a broad signpost AVM system. That is, the "item benefit-cost ratio" for this savings divided by the total broad signpost cost is 0.594. The high case data collection benefit yields present value savings of $7,331,600 with an item B/C of 1.148 for checkers alone.

The data collection savings are the most confident of the three types of bus savings.

5.2.2. Layover Benefits. The time a bus spends outside of the garage is called platform time. Total bus platform time is made up of deadhead (which is non-revenue travel time), revenue running time on routes, and layover. Layover is the time allowed in the schedule at the end of revenue runs. Part of this time is for driver rest breaks and the rest is a cushion to absorb late arrivals at the end of one run and still permit the next run to begin on time. This portion of layover, sometimes called slop, is a form of insurance against spiraling and self-perpetuating increases in late buses. However, excess layover is expensive insurance, paid for with an idle bus and driver.

Excess layover is a logical target for AVM. Exact vehicle location information for an entire route or set of routes enables a central dispatcher to implement operational strategies and control methods designed to minimize disruptions in service and to maximize schdedule adherence. If these controls are successful, the variation in running time can be reduced, thus cutting the need for slop. Reducing average layover for a property immediately increases the productivity of vehicles and drivers. If

overall productivity can be increased, the property can continue to offer the same service and headways with fewer vehicles.

The best available evaluation of AVM-type bus control strategies comes from Dublin, where a manual radio control system was used to provide near real-time position location information for use in controlling fleet movements. The Dublin data reports a reduction of .93 minutes (25%) in average passenger wait time following route instrumentation and control. Since the reduction in wait time was due to better schedule adherence, we use this data as the key to AVM's impact on layover in the base case. For the low benefit, we credit AVM with reducing layover by the absolute value of .93 minutes, and in the high case we credit AVM with a 25% reduction.

The base case factors are considered fair though conservative. The Dublin data represent the average reduction in wait time along the entire route; deviations from schedule may be aggravated and cumulative over distance and should be much greater at and near the end of a route than they are at or near the start of that route. Thus a reduction of .93 minutes in mean wait time understates the reduction at the end of the route, which is where the

aggregate of all delays must be absorbed with layover. The test route in Dublin had a one way run time of 25 minutes. The average route in the base case fleet has an average one way run time of 68.2 minutes. This longer run time permits greater fluctuations from schedule, so that if the base case fleet equals Dublin's degree of control effectiveness, one can argue that the results are likely to be greater. The control techniques in Dublin were neither automated nor continuous. One may expect that a well-designed and managed AVM system should at least equal Dublin's radio control system in effectiveness. Finally, no data have been found to contradict the Dublin results.

Our base case fleet has an average layover of 13.67 minutes, which is 16.7% of total platform time and 20% of average one way run time. Applying the Dublin factors to the base case reduces layover by .93 minutes to 12.74 minutes (19% of run time) for the low benefit and by 25% to 10.25 minutes (15% of run time) for the high benefit.

The model converts layover reductions into vehicle savings only after shrinking the target vehicle population by factoring out the maintenance float and those vehicles on routes with headways of <u>over</u> ten minutes. (On long headway routes, layover is dictated by the decision to provide less

frequent service and long layover on these routes is not a sign of slop). The final relationship between percentage reductions in layover (which are entered into the model) and percentage reductions in the total bus fleet (which are determined by the model) is on the order of twenty five to one (25:1). That is, a 25% reduction in layover yields approximately a 1% reduction in the total fleet.

AVM produces layover savings of seven buses in the low case and 22 buses in the high case. Only limited O&M savings accompany these reductions because the savings were achieved out of idle layover time, not running time. Twelve drivers or the equivalent in payroll hours may be released through attrition in the low case, while 38 may be released in the high case. The present value of the capital, O&M, and personnel savings is $1,714,000 in the low case, with an item B/C of 0.269; and $5,977,000 in the high case, with an item B/C of 0.936. These are confident estimates as long as AVM is applied and exploited effectively by operating managers.

5.2.3 Load Factor Improvements. Regular users of bus service adapt their behavior to the quality of that service. They learn the schedule and establish a level of confidence in the service. If the schedules are dependable, passengers

are more inclined to arrive at the bus stop shortly before the bus is due since they are confident that the bus will be on time. If the arrival times are less predictable, with buses frequently early or late, passengers tend to arrive earlier to reduce the risk of missing an early bus, thus extending their average waiting time.

The AVM Project Office at TSC has developed a managerial strategy, presented at Appendix D, which exploits this apparent behavioral tendency to vary passenger arrival time based on the variability of service. If AVM enables transit managers to improve schedule adherence or reliability, they can capture benefits by lengthening the headway between buses without changing the perceived passenger waiting times. The extended headway reduces the vehicle and driver assets invested in the route and increases the average load factor on the remaining buses. These increased loads can be spread more evenly as "bunching" of the buses can be eliminated with AVM. Potential changes in load factors, of course, will vary in relation to the quality of schedule adherence prior to implementation of any controls. A route with good headway adherence and little bunching will achieve minor load factor increases and vehicle savings, but a route with poor headway adherence and significant bunching may

garner important benefits if all vehicles are not already loaded to capacity.

Load factor improvements are separate and distinct from layover reductions. Load factors focus on operating efficiencies during the revenue run and attempt to reduce the number of revenue runs, while layover savings arise from reducing unnecessary idle time at the ends of revenue runs.

Average load factor improvements of one and ten percent have been adopted as the low and high base case benefits. Both factors represent relatively good initial schedule adherence and modest improvements in layover. Calculations were performed only after the base fleet had been reduced by the layover savings in order to avoid double counting. The target fleet population was further restricted to vehicles operating during peak hours only on headways of ten minutes or less.

Load factor improvements save ten vehicles for the low benefit input, and 91 vehicles for the high benefit input. Payroll dollars equivalent to seventeen drivers can be freed in the low case and 157 in the high case (out of an initial base case force of 4,900 drivers). The present value of the low benefit is $3,197,000, for an item B/C of 0.50; the

present value of the high benefit is $28,181,000, for an item B/C of 4.412. In the absence of supporting experimental data, the load factor benefits must be regarded as the most speculative of the bus benefits.

5.2.4 Composite Bus Results. Table V-1 is the bus benefit output from the computer model. It shows each source of savings individually, including all of the elements which were summarized in the preceding sections. All dollar costs and savings are expressed in present values discounted at ten percent. The lower part of Table V-1 shows the total savings, which are $8,707,400 in the low case and $41,,490,700 in the high case. These benefits are compared with the low cost individual AVM and with the bus's share of the low cost multiple user AVM. (Both are broad signpost location systems.) The single user, total benefit cost ratio is 1.363 in the low case and 6.496 in the high case. Participation in the base case multiple user system has a negligible impact on these results.

TABLE V-1

Cost Benefit Summary for: Bus
(Dollar Values in Thousands)

Savings Source:		Layover Reduction Low	Layover Reduction High	Load Factor Improvement Low	Load Factor Improvement High
% Change		6.8	25.0	1.0	10.0
Vehicles Saved		7.	22.	10.	91.
Capital	$	375.5	1294.4	558.6	5302.8
O&M		70.5	562.7	751.4	5996.4
Sub Total	$	446.0	1857.1	1309.1	11299.1
Item Benefit/Costs					
Single User		0.070	0.291	0.205	1.769
Multi-User		0.070	0.292	0.206	1.776
Drivers Saved		12.	38.	17.	157.
Salary	$	1034.8	3361.1	1539.2	13769.9
Overhead+Ben		233.9	759.7	347.9	3112.2
Sub Total	$	1268.7	4120.8	1887.1	16882.1
Item Benefit/Cost:					
Single User		0.199	0.645	0.295	2.643
Multi-User		0.199	0.648	0.297	2.654

		Data Collection Low	Data Collection High
Personnel Saved		40.	40.
Salary	$	1897.8	3665.8
Overhead+Ben		1897.8	3665.8
	$	3795.6	7331.6
Item Benefit/Cost:			
Single User		0.594	1.148
Multi-User		0.597	1.153
Total Savings	$	8707.4	41490.7
System Costs:			
Single User		6386.7	6386.7
Multi-User		6360.7	6360.7
Benefit/Cost Ratio			
Single User		1.363	6.496
Multi-User		1.369	6.523

Changing the location system has a major impact on the results since the higher costs translate into direct reductions of the B/C. Table V-5 at the rear of this chapter summarizes the full range of B/C ratios for all fleets and all location systems, but Figure V-4, shown on the next page, is a graphic display of the impact of the four single user bus location system costs on the low and high B/C ratios. The horizontal lines connect the high and low B/Cs for each location system. Higher lines represent higher cost technologies and the dashed perimeters surrounding these cost lines represent the effect on the B/C ratio resulting from variations in system cost estimates (see paragraph 3.2.3) of: ±6.5% for dead reckoning; ±20% for sharp signpost; ±18% for radio frequency; and ±5% for broad signposts. As can be seen, cost variations or selection of higher cost location systems can significantly erode potential payoffs in terms of the B/C ratio.

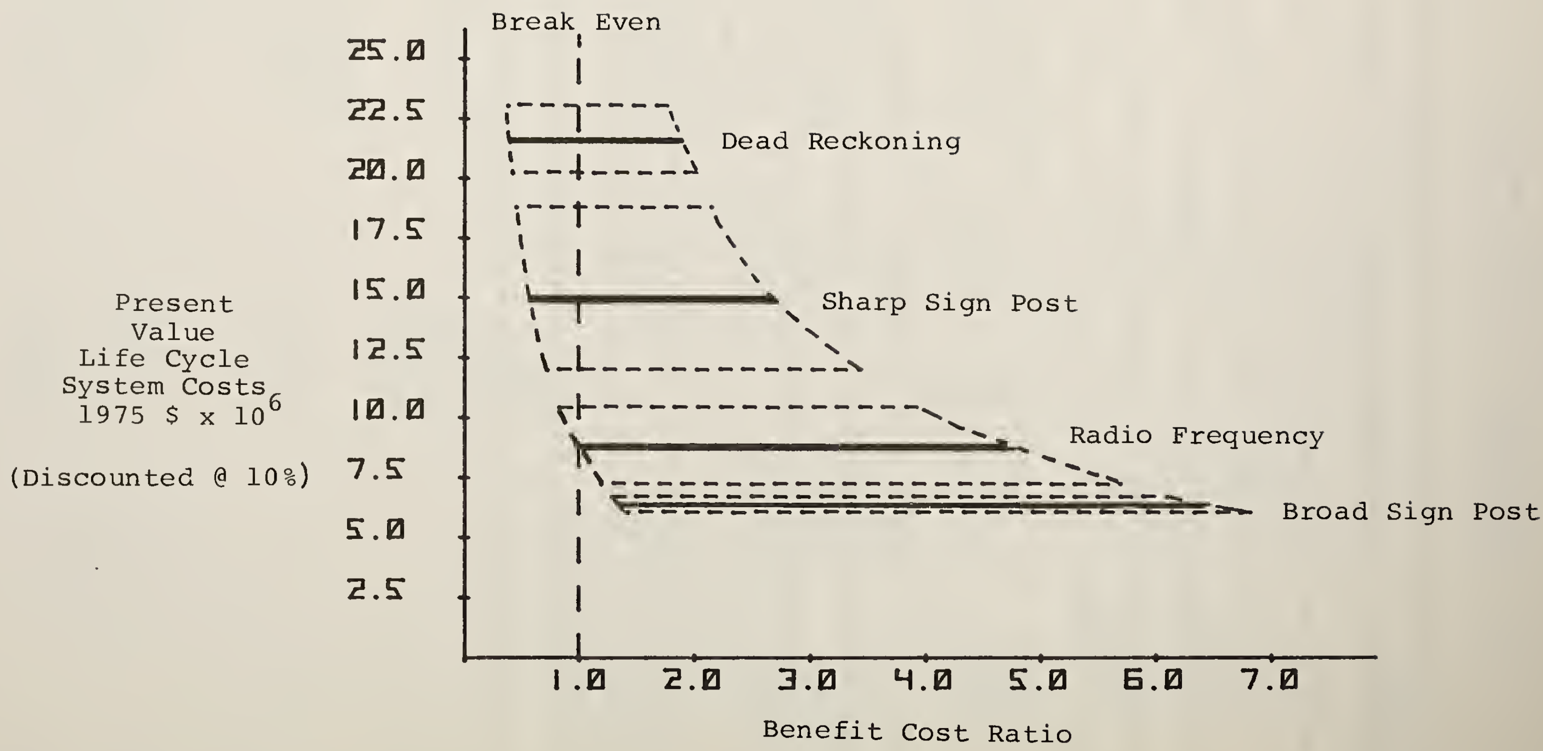


FIGURE V-4

TECHNOLOGY COSTS AND BENEFIT/COST
RATIOS FOR BUS

5.2.5 Bus Conclusions. The low case B/C is the natural place to turn for a single indicator about the viability of AVM as an investment. Before assuming the attainability of a B/C of 1.363, one must consider the three sources of the benefits:

Benefit Source	Item B/C	% of Total B/C
Data Collection	0.594	44%
Layover	0.269	20%
Loadfactor	0.500	37%
Total Bus Benefit	1.363	101%
		(rounded)

Data collection is the largest portion of the total B/C. While the benefit has been calculated conservatively, its source is strictly the reduction in manual checkers. This makes the payoff heavily dependent on the number of checkers employed by a particular property.

Layover reductions are a traditional benefit connected with AVM fleet control, yet it produces only a small item B/C. Its application in this analysis is a conservative extension of the Dublin data, which is the only quantitative evidence supporting such improvements.

Over a third of the total payoff comes from the load factor improvements, which are considered speculative, and will require an extensive measurement of actual performance improvements to be validated. If this item B/C is omitted, the total payoff drops to .863, which is marginal even considering the conservative nature of the two remaining elements.

5.3 AVM Benefits for the Police

5.3.1 AVM Impact on Police Operations. Police cruisers are assigned to beats and districts to conduct preventive patrols and respond to emergency and routine service calls. AVM is attractive to law enforcement officials because the ability to dispatch the closest patrol car to an emergency offers the opportunity to shave seconds and perhaps minutes from average response times, thus increasing the likelihood of apprehensions and improving protection of people and property. Police response time savings are of interest from a transportation perspective because they translate into mileage reductions and operating efficiencies.

The St. Louis experiment with a dead reckoning AVM achieved response travel time saving of 10%, and analysis indicates that this equates to a similar or slightly smaller reduction in mileage travelled (Larson, Roos). Based on this,

percentage reductions in police response miles of 2% and 10% were adopted as the base case low and high benefits.

Mileage devoted to preventive patrol is not eligible for saving. Fifty percent of base case mileage is eliminated on this basis and AVM savings are applied only to the remainder. The total miles which can be saved are equivalent to 11 cruisers in the low case and 53 in the high case (from a fleet of 1330). Full O&M and personnel savings are associated with each cruiser. O&M includes costs of mileage and ownership. Personnel includes the average $21,800 salary and equivalent benefits for each of the 3.3 patrolmen who staff a cruiser. Personnel savings total 35 in the low case and 176 in the high case. Both targets are assumed to be achieved by attrition at a rate of 10% applied to the initial patrol force of 4,389.

The TSC estimate of vehicle savings was tested against the parameters of the Jet Propulsion Laboratory's (JPL) police AVM model, which derives efficiency improvements from location system accuracy relative to fleet and area dimensions. TSC vehicle savings were well within the targets that the JPL model established for UMTA specified AVM location system accuracies equivalent to those in the

UMTA specification and applied within the base case dimensions.

5.3.2 Police Results. Table V-2 displays the detailed benefit and payoff data for the police. The low benefits produce present value savings of $10,006,500, 96% of which flow from personnel savings. The remaining 4% are a combination of vehicle capital and O&M savings. These savings produce a single user B/C of 2.386 for the low cost radio frequency location system. This is the largest value for a low benefit B/C for any single user of AVM in the study. Present value savings and B/C in the high case are nearly five times greater than the low case, reflecting the difference in AVM impacts. Improvements in B/C due to multiple user cost sharing are on the order of 1%.

The large personnel costs associated with each police cruiser provide leverage which increases the dollar benefits of AVM impacts. These substantial benefits enable the police to absorb a greater range of increased system costs before dropping below the breakeven point. Figure V-5 shows that for low benefits only the two highest cost location systems dip below breakeven conditions.

TABLE V-2

Cost-Benefit Summary for: Police
(Dollar Values in Thousands)

Savings Source:		Response Time Reduction Low	High
% Change		2.0	10.0
Vehicles Saved		11.	53.0
Capital	$	109.6	580.9
O&M		323.0	1615.2
Subtotal	$	432.6	2196.0
Item Benefit/Cost:			
Single User		0.103	0.524
Multi-User		0.104	0.529
Patrolmen Saved		35.	176.
Salary	$	4786.9	23332.8
Overhead+Ben		4786.9	23332.8
Sub Total	$	9573.9	46665.7
Item Benefit/Cost:			
Single User		2.283	11.129
Multi-User		2.305	11.235
Total Savings	$	10006.5	48861.7
System Costs:			
Single User		4193.1	4193.1
Multi-User		4153.7	4153.7
Benefit/Cost Ratio:			
Single User		2.386	11.653
Multi-User		2.409	11.763

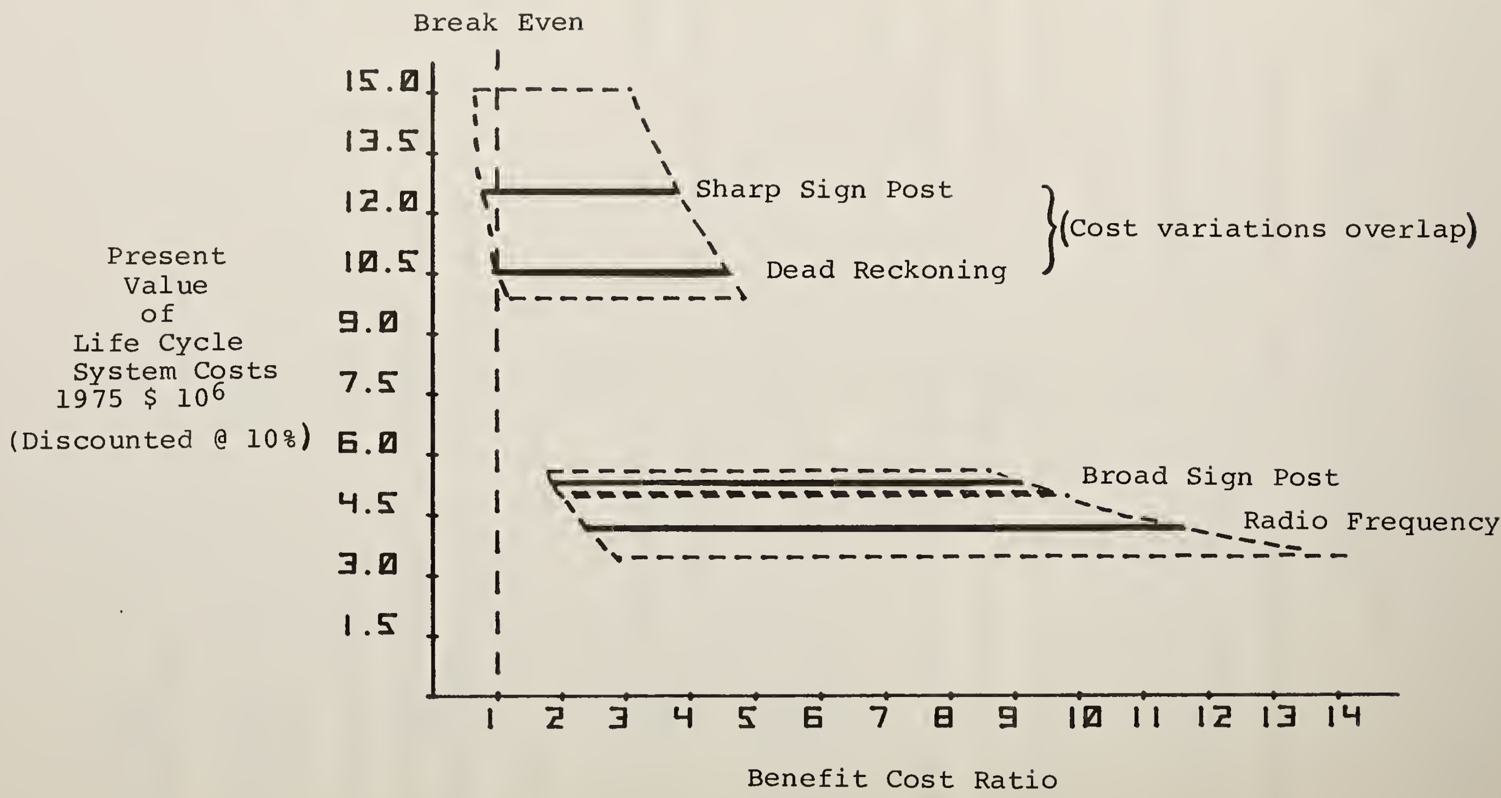


FIGURE V-5

TECHNOLOGY COSTS AND BENEFIT/COST
RATIOS FOR POLICE

The results of this study, Doering's work in Orlando, the expansion of the FLAIR AVM in St. Louis, and the JPL analysis all reinforce the conclusion that AVM offers significant benefits to police and public safety managers.

5.4 AVM Benefits for the Taxi

5.4.1 Impact of AVM on Taxi Operators. Radio controlled taxi operations are analagous to police operations in that dispersed vehicles are assigned to random service calls. Knowledge of vehicle location permits assigning the closest car to each ride request with the goal, in this case, being a reduction of non-revenue miles.

The base case fleet accumulates 50% of total miles in non-revenue operations. Part of this non-revenue movement (deadhead) is unavoidable because passenger destination and subsequent pick up points do not coincide. Simulation conducted at TSC indicates that this unavoidable deadhead amounts to 18% of total miles, leaving 32% of total miles as avoidable deadhead. Avoidable deadhead is cruising in search of fares and returning from passenger drops to central pick up or dispatch points. AVM can help reduce this portion of deadhead.

Analysis and extrapolation of St. Louis police data and consultation with taxi operators résulted in base case low and high benefits for reductions in avoidable deadhead mileage being set at 10% and 20%. This translates into vehicle savings of 33 in the low case and 66 in the high case (out of a fleet of 800). Capital and total O&M savings are associated with these savings as are 69 drivers in the low case and 138 drivers in the high case. Since these jobs are paid on a commission basis, the sole value to the operator is the reduction of fringe benefits worth $1,350 annually per driver.

5.4.2. Taxi Results. Table V-3 displays the model benefit output for the base case taxi fleet. Reduction of deadhead miles yields total present value savings of $2,059,000 in the low case and $4,110,100 in the high case. The respective B/C's are 0.743 and 1.482 for the taxi alone scenario. Participation in a multiple user system improves the taxi B/C's by nine percent, but the taxi remains well below the breakeven B/C point for low benefits. Figure V-6 shows that taxi B/C's exceeded 1.0 only for the high benefits when combined with the two lowest cost systems.

The taxi benefits are in marked contrast with the police. Taxis achieve a larger fleet reduction of 4% in the low case

TABLE V-3

Cost-Benefit Summary for: Taxi
(Dollar Values in Thousands)

Source of Savings:	"High-Flagging" Reduction	
	Low	High
% Change	0.0	0.0
	Reduce Dead-Head Miles	
% Change	4.1	8.2
Vehicles Saved	33.	66.
Capital	$ 239.1	485.7
O&M	1238.5	2476.9
Sub Total	$1477.6	2962.7
Item Benefit/Cost:		
Single User	0.533	1.068
Multi-User	0.585	1.174
Drivers Saved	69.	138.
Salary	$ 0.0	0.0
Overhead+Ben	581.5	1147.5
Sub Total	581.5	1147.5
Item Benefit/Cost:		
Single User	0.210	0.414
Multi-User	0.230	0.455
Total Savings	$ 2059.1	4110.1
System Costs:		
Single User	2773.1	2773.1
Multi-User	2523.7	2523.7
Benefit/Cost Ratio:		
Single User	0.743	1.482
Multi-User	0.816	1.629

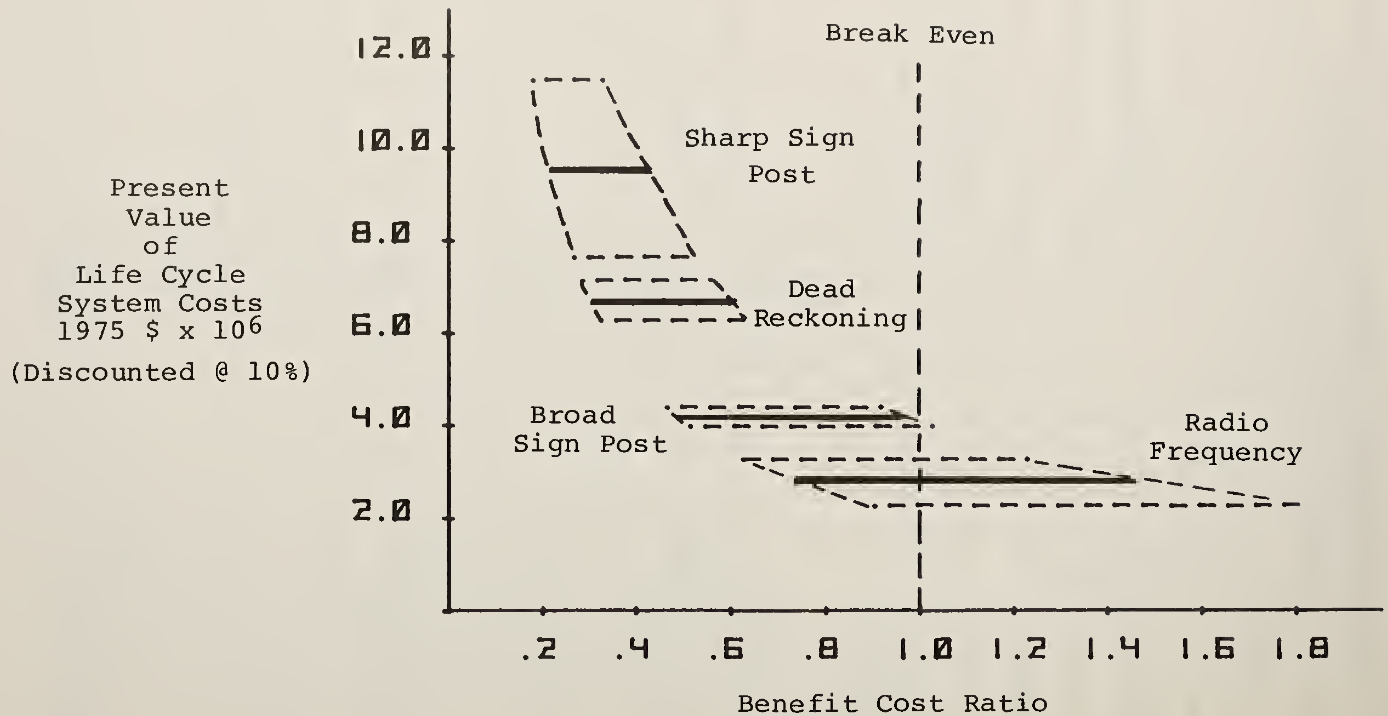


FIGURE V-6

TECHNOLOGY COSTS AND BENEFIT/COST RATIOS FOR TAXI

while the police fleet reduction was only 0.8%. Despite this, the taxi low case single user B/C is 0.743 while the comparable police B/C is 2.386. The great difference is explained by personnel costs. This category, which accounted for 96% of police savings, comprises only 28% of the taxi savings. A saved taxicab has a small total of avoided employee benefits compared to a saved patrol car which has over three salary and overhead units associated with it.

Taxi fleets achieve the greatest benefits from AVM in terms of fleet reduction and vehicle productivity. Ironically, taxi operators may not be able to afford these improvements at current AVM cost estimates because the salary structure of the industry precludes capture of labor savings.

5.5 Total Multiple User AVM Benefits

AVM benefits for the multiple user fleet are a summation of individual fleet savings; there are no operational impacts and benefits of AVM attributed to the shared system. Table V-4 presents the total results of all fleets for comparison purposes. Figure V-7 does the same for the multiple user payoff envelope.

TABLE V-4

Cost-Benefit Summary for: Multi-User
(Dollar Values in Thousands)

Savings Source:	Low	High
Bus	$ 8707.4	41490.7
Police	10006.5	418861.7
Taxi	2059.1	4110.1
Capital Savings	$ 1285.8	7663.7
O&M Savings	2383.4	10651.2
Personnel Savings	17106.8	76147.7
Loss Adjustments	0.0	0.0
Total Savings	$20773.0	94462.6
System Costs:		
Multi-User (broad sign post)	$13038.2	13038.2
Benefit/Cost Ratio:		
Multi-User	1.593	7.245

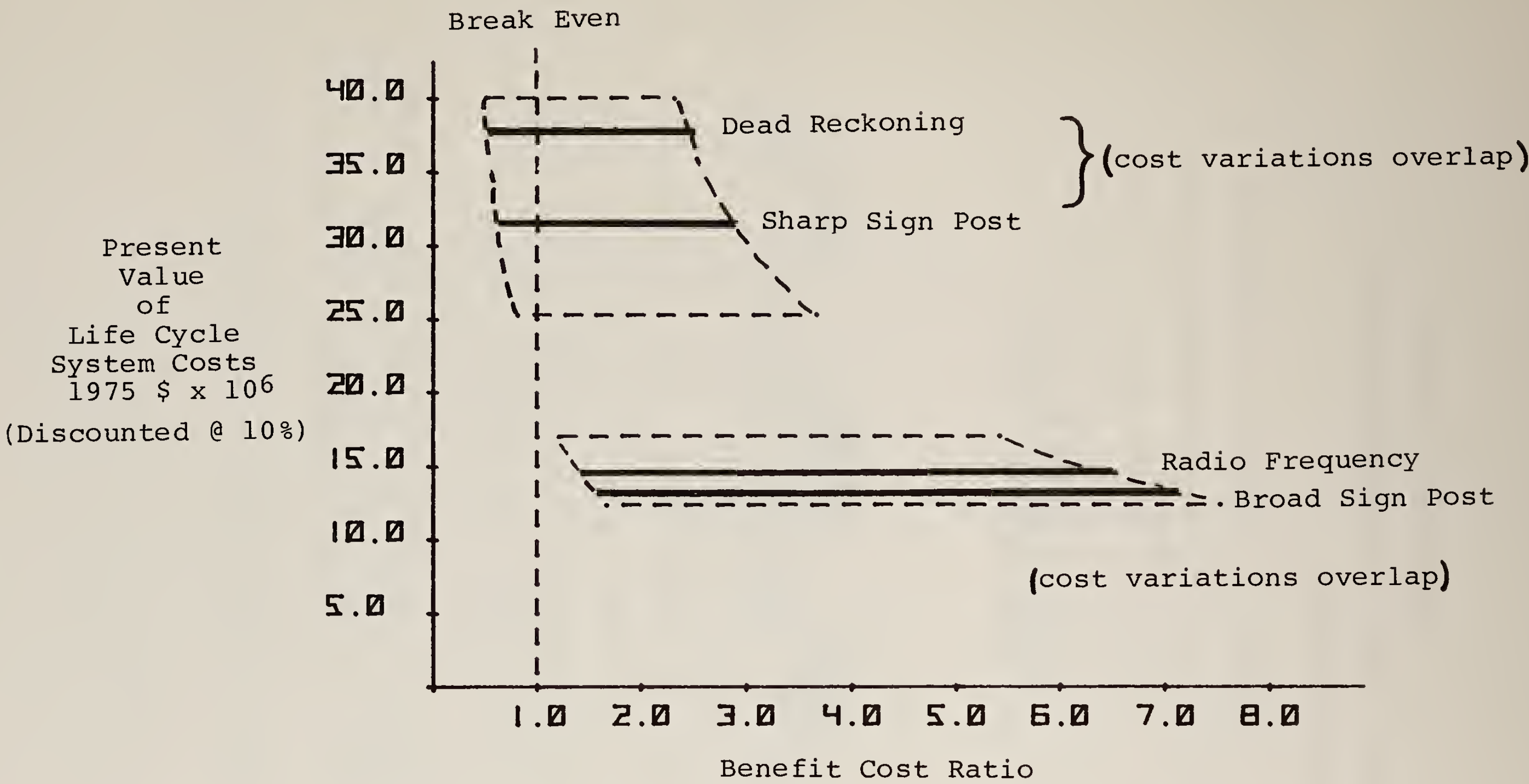


FIGURE V-7

TECHNOLOGY COSTS AND BENEFIT/COST RATIOS FOR MULTIPLE USER FLEET

As a final summary, Table V-5 summarizes B/C's for all fleets and location systems.

TABLE V-5

AVM INVESTMENTS PAYOFFS
(Benefit/Cost Ratios)

	Broad Signpost		Radio Frequency		Sharp Signpost		Dead Reckoning	
Benefit Estimate:	Low	High	Low	High	Low	High	Low	High
Bus Alone	1.36	6.50	0.98	4.69	0.58	2.76	0.40	1.92
Bus Shared	1.37	6.52	*	*	*	*	*	*
Police Alone	1.89	9.21	2.39	11.65	0.80	3.89	0.95	4.63
Police Shared	2.41	11.76	*	*	*	*	*	*
Taxi Alone	0.49	0.98	0.74	1.48	0.22	0.43	0.31	0.61
Taxi Shared	0.82	1.63	*	*	*	*	*	*
TOTAL MULTIPLE	1.59	7.25	1.44	6.54	0.65	2.99	0.55	2.51

*Not available.

VI SENSITIVITY ANALYSIS

6.1 Introduction

An analysis was conducted to examine the impact of variations in the key assumptions used in the calculation of AVM related benefits. In some cases, the range of variation was expanded to extremes to illuminate any possible discontinuities and limitations of the model or of AVM applications.

The sensitivity results should be used to develop only the broadest generalities regarding AVM utility. Though the model utilized to obtain the information is extremely flexible the precise makeup of user fleets and their distribution will, in the real world, vary in a discontinuous fashion. Thus, large excursions from the base case should be described individually using actual configurations and information about the site in question. For purposes of the urban size analysis, the assumptions used are considered as gross approximations of the changing service characteristics that exist in different urban environments.

6.2. Approach

The model used to generate the results of this study was developed to be an extremely flexible tool, readily adaptable to support sensitivity analysis of this type. However, once a number of data points for each case had been computed a regression analysis was then used to develop the complete data set. While most of the relationships appear to be linear, a least squares parabolic solution gives the most consistent fit.

Analyses were conducted for the low range of individual user costs and benefits by varying fleet sizes, areas, and percentage improvements. In addition to individual cases, estimates of the trends of benefits and costs in different urban size locations were also made. These estimates reflect an assumed exponential relationship between reduced fleet sizes and operational descriptors such as run times.

6.3 Single User Sensitivities

6.3.1 Bus. All of the following figures are presented as variations around the base fleet of 2400 vehicles operating on 3825 route miles. Cost estimates are for a broad signpost system utilized only by the bus fleet. Only the low estimates of benefits are analyzed.

6.3.1.1 Sensitivity to Fleet Size. Variation in expected total costs and total benefits (low range only) are shown in Figure VI-1.

Note that the benefits shown, yield a value even when there are only a few vehicles in the fleet. This situation reflects the present value of benefits of decreasing the fixed "field checker" work force by some 40 people.

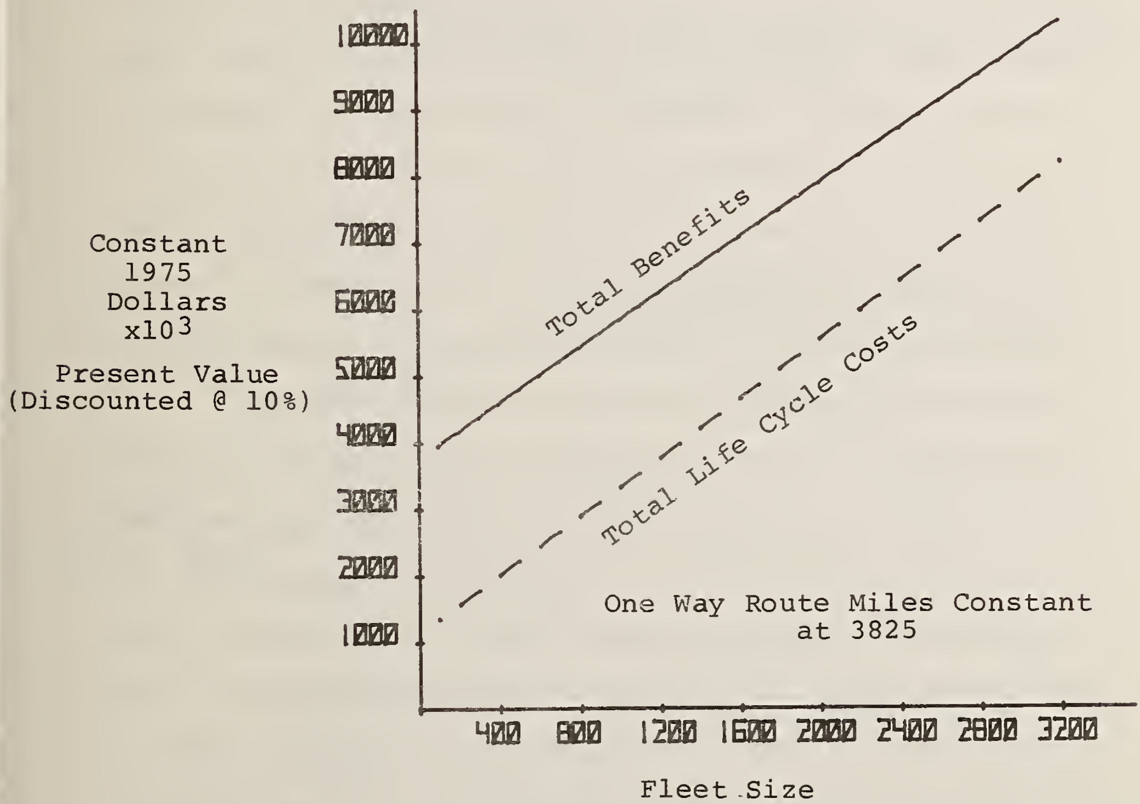
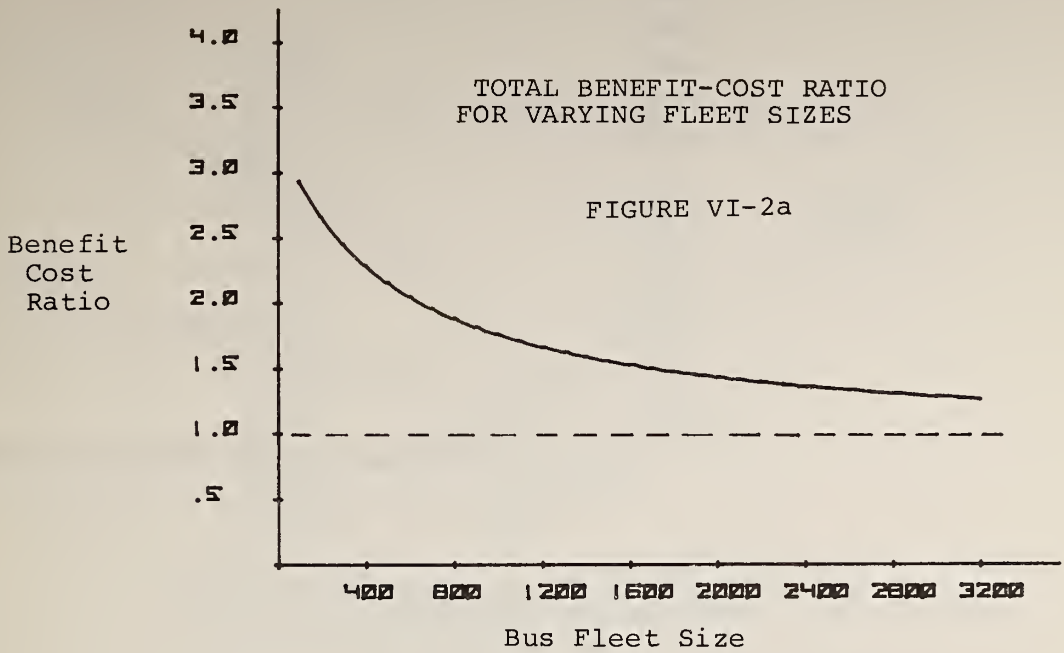


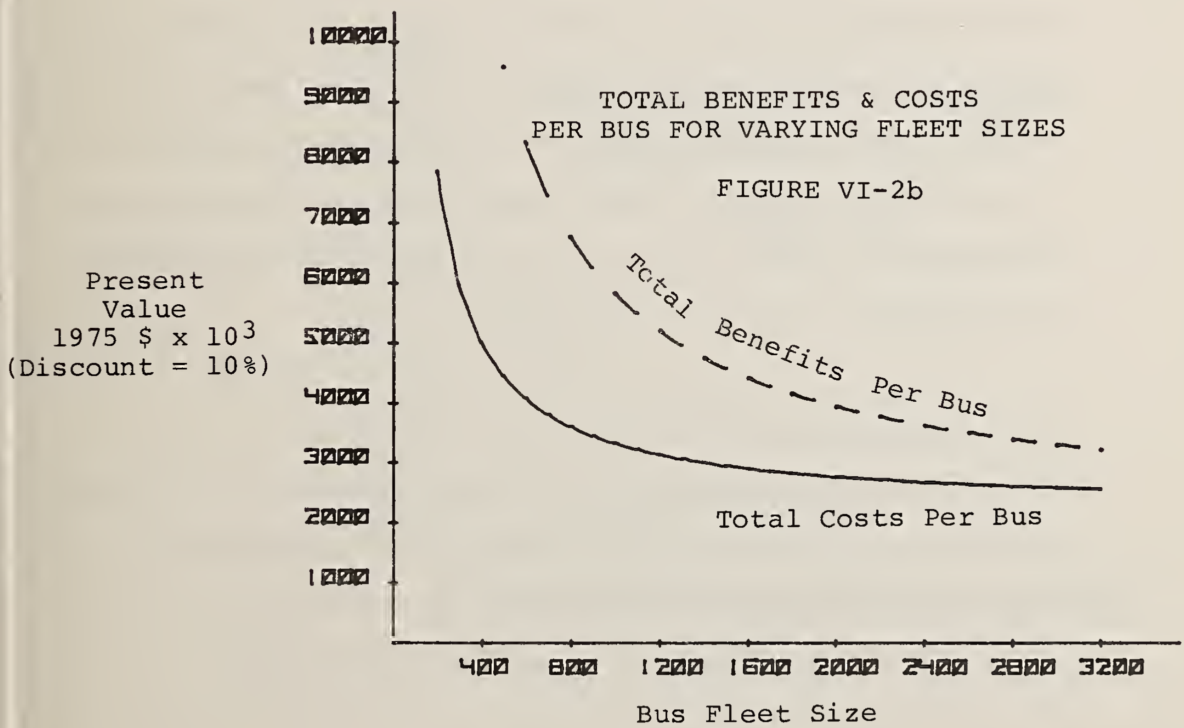
FIGURE VI-1

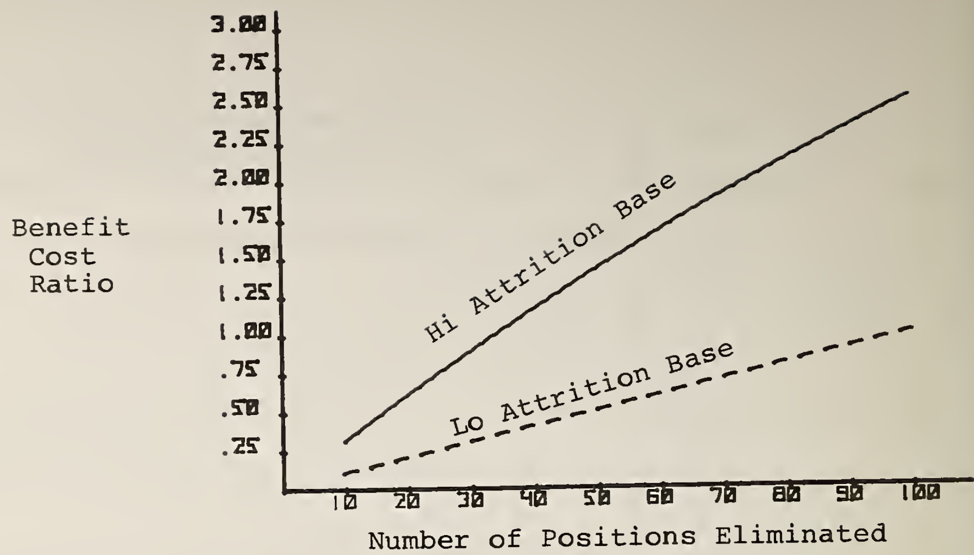
TOTAL COSTS AND BENEFITS FOR BUS ONLY OPERATIONS

As the fleet size increases so do the costs and benefits though the benefits grow at a slower rate than costs. Thus the benefit cost ratio reaches a limiting point at about 2000 vehicles. This is shown in Figure VI-2A. Figure VI-2B illustrates the constancy of benefits attributable to each bus and the decaying nature of the costs per bus, reaching a lowest figure of about $2600.

The benefits shown, however, are not considered realistic at fleet levels much below 1200 vehicles, as the route miles and area were held constant in this analysis of fleet size variations. The implicit effect of shrinking the total fleet without changing area, or route miles, would be to produce a bus system that has one way run times of over two hours which would more nearly represent a commuter operation than that of a typical fixed route transit system. Additionally, the benefits derived for the base case from the attrition of field checkers is not directly dependent upon either fleet size or the installation of AVM but rather on automatic passenger counters which coincidentally, but perhaps unnecessarily, transmit their information in real-time by means of AVM. The effect of varying the number of checkers for different attrition bases is shown in Figure VI-3.


TOTAL BENEFIT-COST RATIO
FOR VARYING FLEET SIZES
FIGURE VI-2a
Benefit
Cost
Ratio
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
400
800
1200
1600
2000
2400
2800
3200
Bus Fleet Size


TOTAL BENEFITS & COSTS
PER BUS FOR VARYING FLEET SIZES
FIGURE VI-2b
Present
Value
1975 $ x 10^3
(Discount = 10%)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Total Benefits Per Bus
Total Costs Per Bus
400
800
1200
1600
2000
2400
2800
3200
Bus Fleet Size



EFFECT ON BENEFIT COST RATIO OF
REPLACING CHECKERS WITH AUTOMATIC
PASSENGER COUNTERS

FIGURE VI-3

Some properties employ as few as 1 checker for every 300 buses as opposed to 1 for every 40 buses as used in the base case. Thus, it is important to isolate these savings from "operational benefits" that derive from more consistently applicable control strategies that are directly dependent upon postion location information.

These operational benefits result from vehicle and driver payroll savings made possible through reductions in layover time and increases in load factors. The information on costs and operational benefits, both totally and on a per bus basis, are shown in Figures VI-4A and VI-4B.

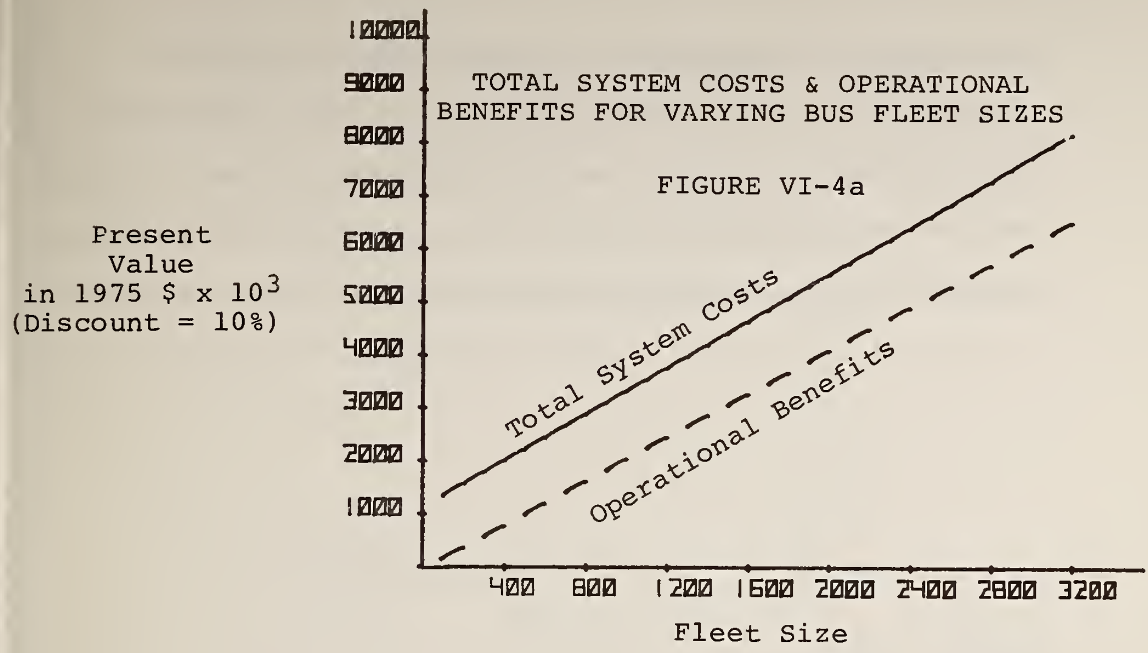


FIGURE VI-4a

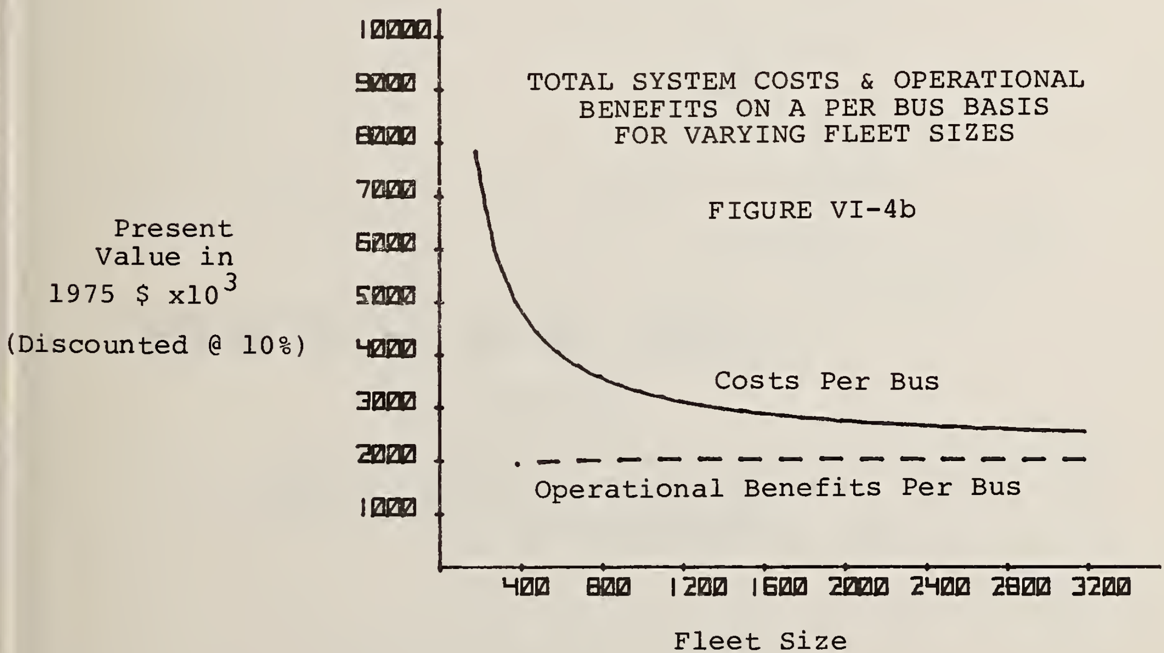
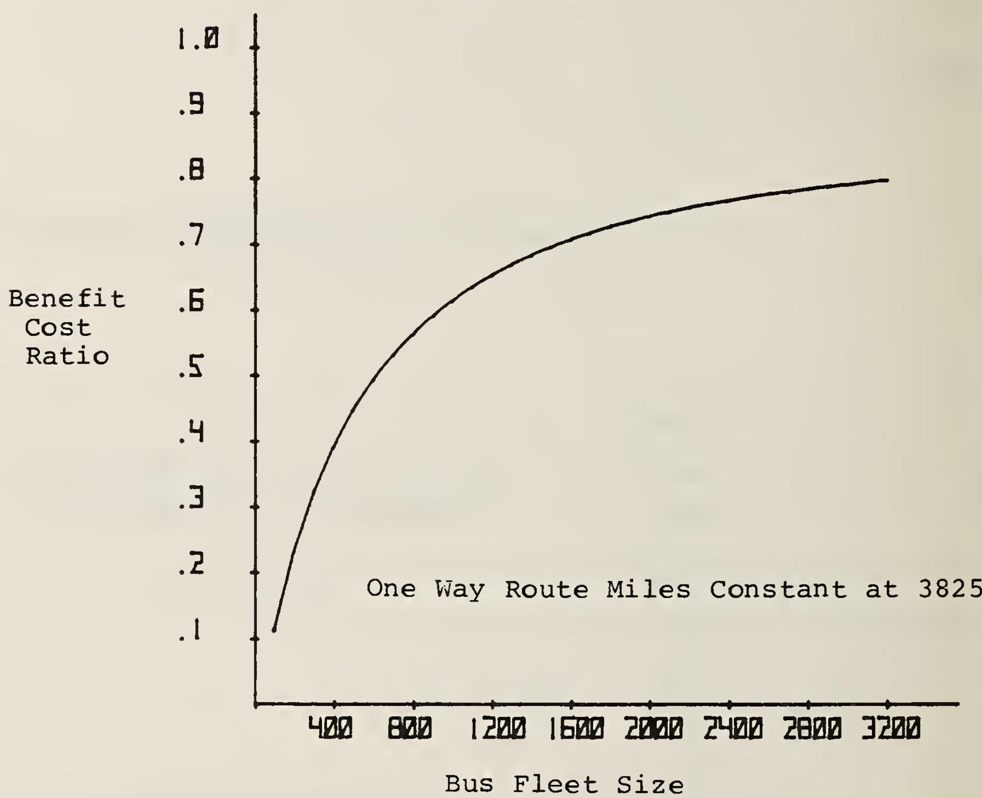


FIGURE VI-4b

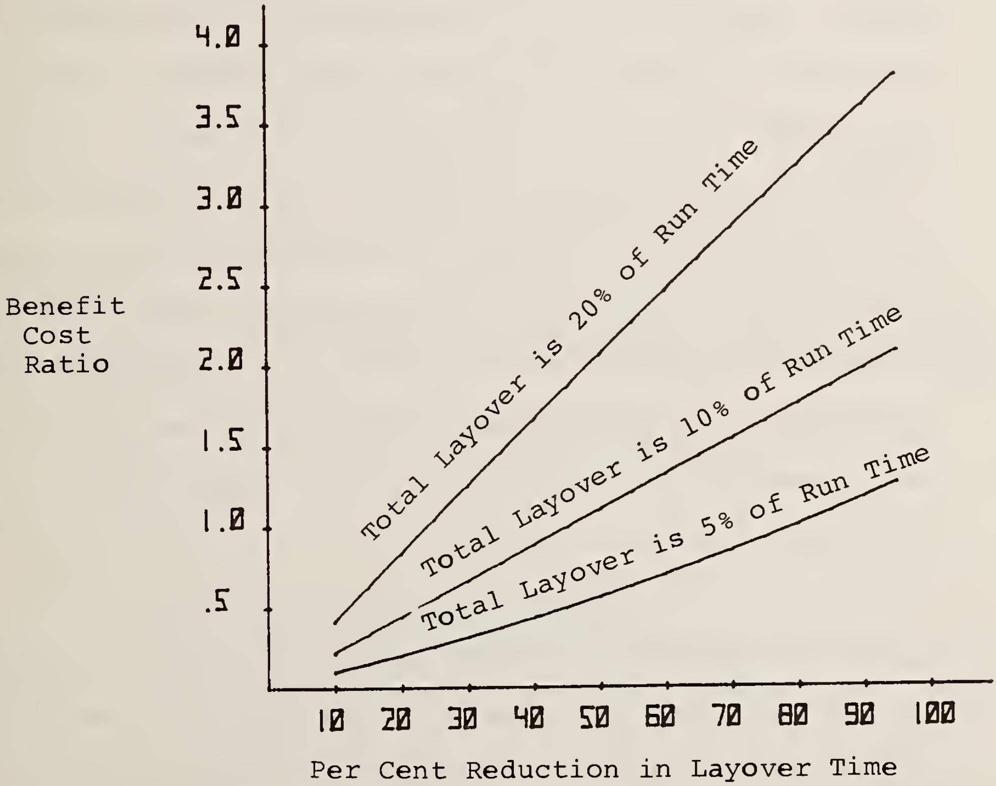
The extent of improvements in these two factors is conservatively assumed to be limited to only those buses out of the total fleet that are operating during peak hours on routes with headways of 10 minutes or less. Figure VI-5 illustrates the resulting operational B/C ratio.



EFFECT ON BENEFIT COST RATIO DUE TO OPERATIONAL SAVINGS AS A FUNCTION OF FLEET SIZE

FIGURE VI-5

6.3.1.2 Sensitivities to Layover Reductions. Because different bus sytems exhibit different layover times when compared against average one way run times, various layover times were analyzed as a function of the degree of improvement or reduction thought possible with AVM. Figure VI-6 illustrates the resultant effect upon the base case benefit cost ratio.

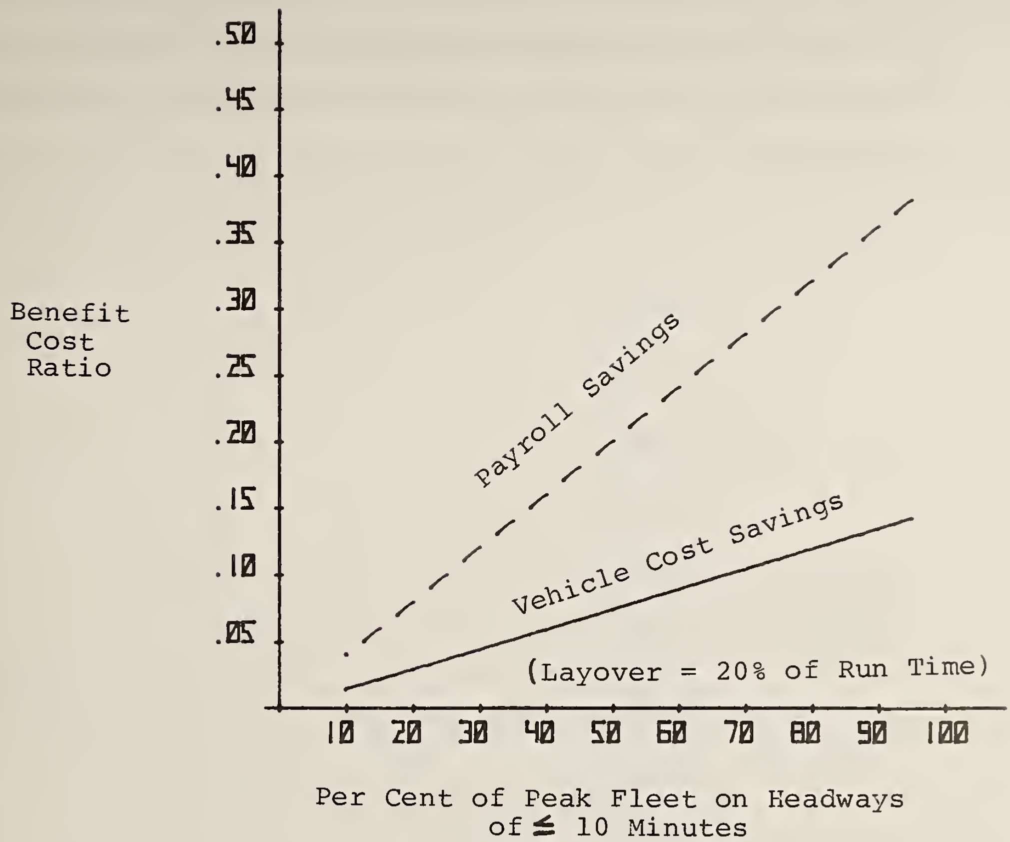


EFFECT ON BENEFIT/COST RATIO
OF DECREASING LAYOVER TIME

FIGURE VI-6

As shown <u>in a case where only layover reductions are made</u>, a 10 percent reduction in layover time, for the base case system operating with layovers equal to 20% of run time, will result in a contribution to the overall benefit cost ratio of approximately 0.4-0.5. This saving is derived not only from the avoided capital and O&M costs associated with the seven buses saved, but reductions in payroll are also present which accounts for over 70% of the total layover savings. Recall that this information is based upon a base case operation where 50% of the buses operate, during rush hour peaks, on headways of 10 minutes or less. As expected, as this percentage increases so do the corresponding savings from layover reductions which now affect a larger percentage of the fleet. The effect is essentially one to one, that is, as the percent of buses on short headways nears 100%, only half of the improvement thought possible for 50% on short headways is needed to return the same benefit. This situation is shown in Figure VI-7.

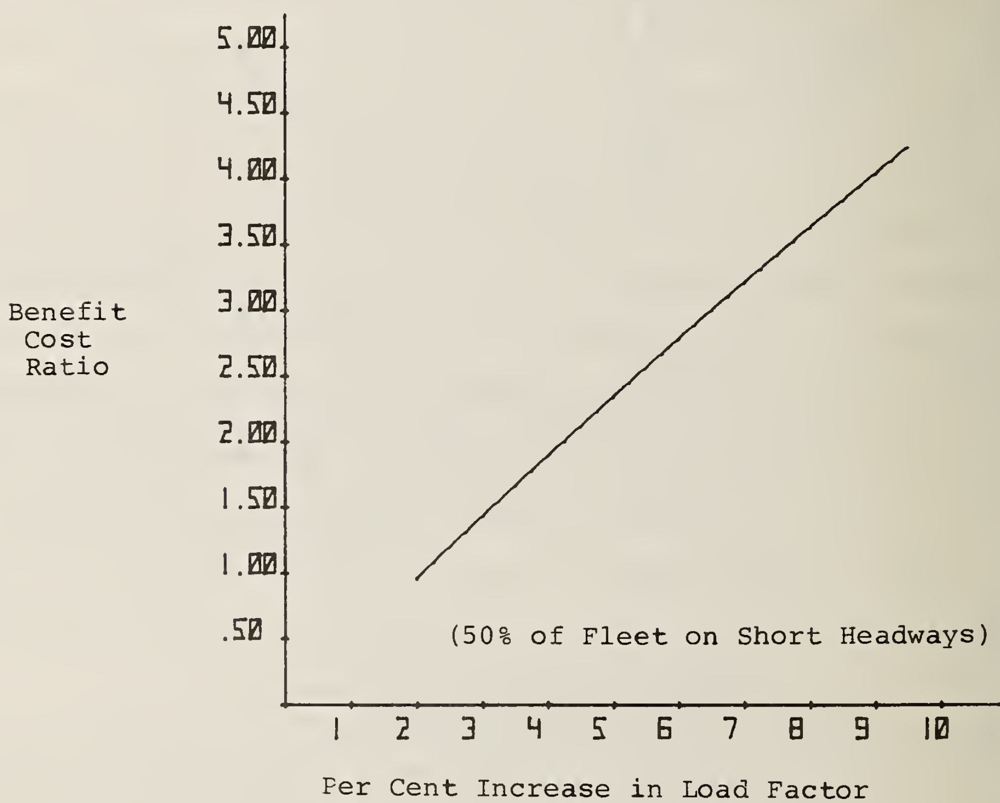
6.3.1.3 Sensitivity to Load Factor Increases. Savings similar to those from layover reductions occur when load factors are increased by using longer headways and tightly controlling schedule adherence. By closely maintaining published schedules, average passenger wait time remains constant and the same volume of service is possible with the



EFFECT ON BENEFIT COST RATIO DUE TO LAYOVER REDUCTIONS

FIGURE VI-7

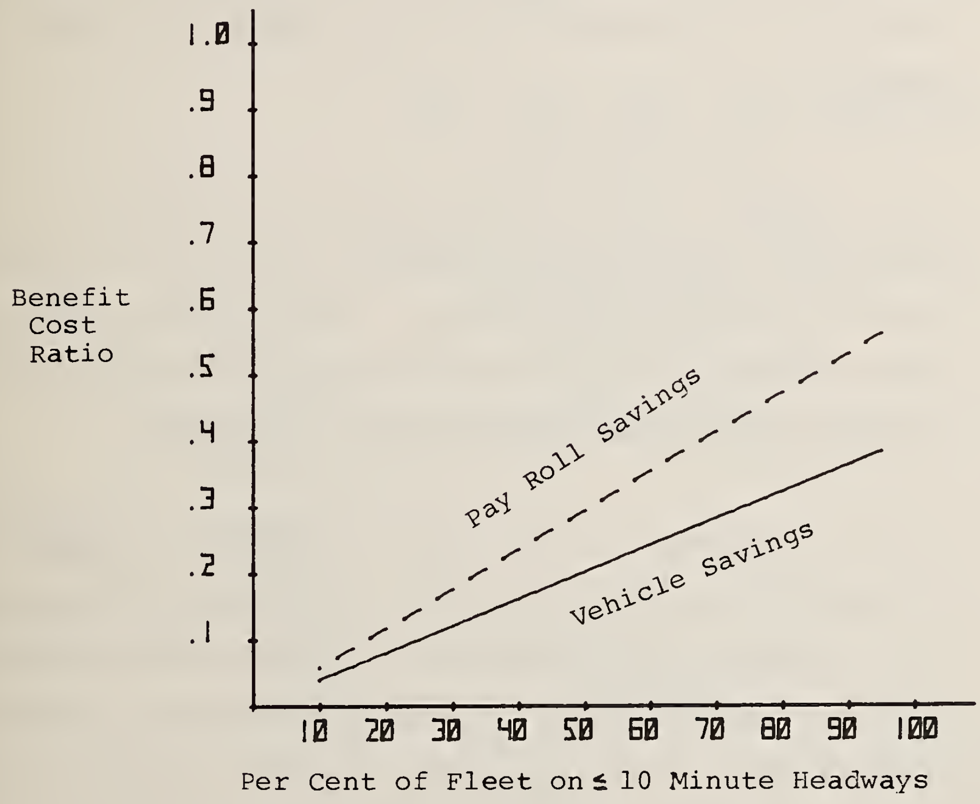
deployment of fewer vehicles which operate at higher but more evenly distributed factors. A percentage improvement in this factor has a more pronounced affect than a corresponding reduction in layover time, as can be seen in Figure VI-8.



EFFECT ON BENEFIT COST RATIO
OF VARYING LOAD FACTOR

FIGURE VI-8

Again, as in the case with layover savings, the more buses operating during peak hour the greater the savings that can be expected for a given percentage improvement in load factor. This situation is shown in Figure VI-9, where the contribution to the overall benefit cost ratio is shown for vehicles and payroll savings arising from a 1% load factor increase.



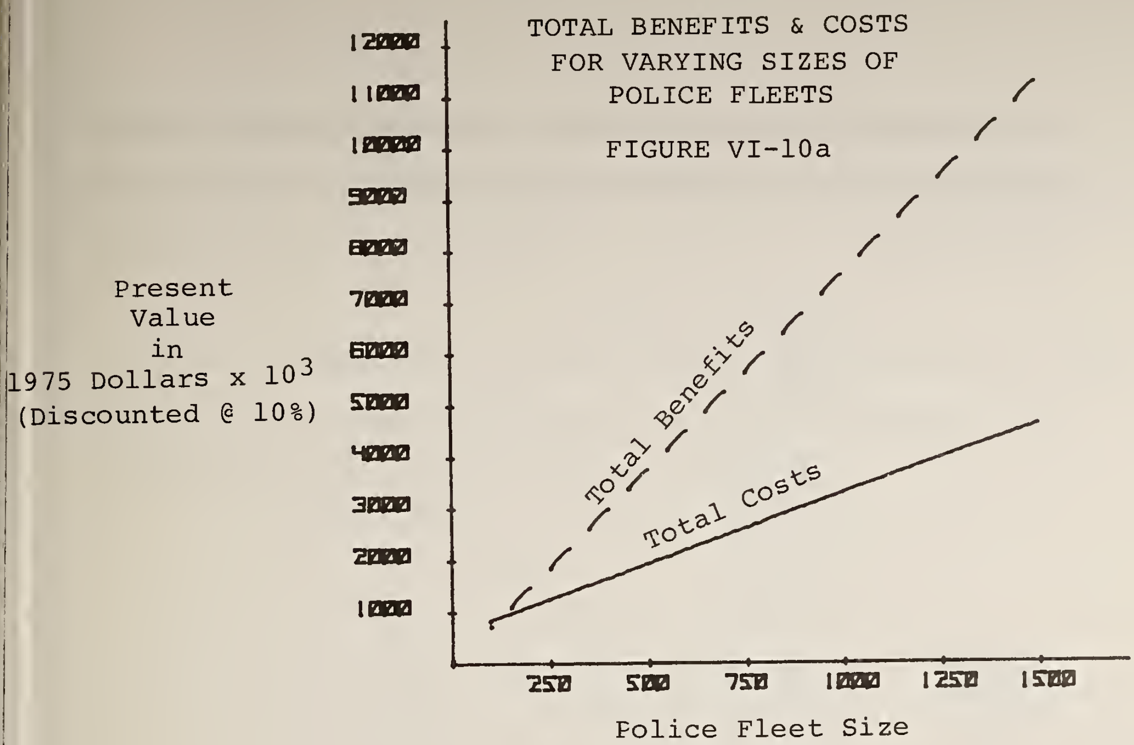
EFFECT ON BENEFIT COST RATIO DUE TO A 1% LOAD FACTOR INCREASE IN BUS LOAD FACTOR

FIGURE VI-9

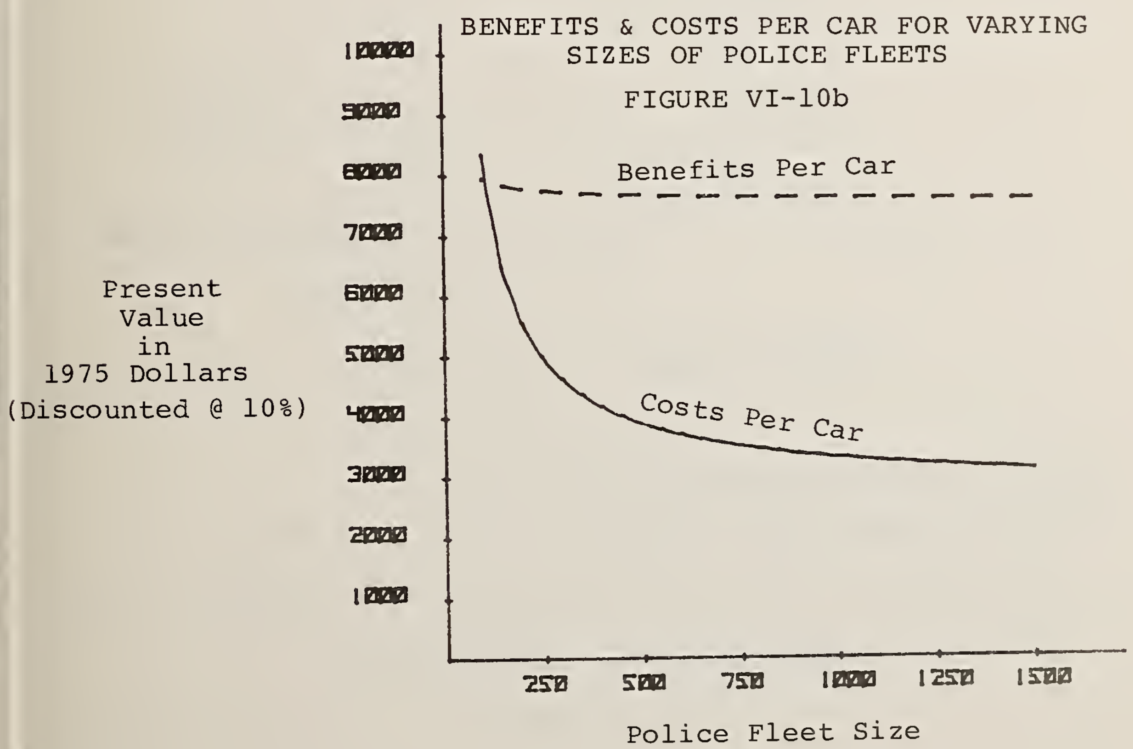
6.3.1.4 Sensitivity to Route Miles. Strictly speaking, a reduction in the number of route miles in a transit system, if nothing else changes, will not return any real benefits per se, but would act only to reduce the AVM system deployment costs. However, if only route miles are reduced, yet the same number of buses generate the same annual mileage, implicitly then, the average number of buses per route must increase. The net effect would be to produce an increase in the percentage of buses operating on short headways.

6.4.2 Police. The following figures are based on variations around the base fleet of 1330 police vehicles operating over 475 square miles. Cost estimates are for a radio frequency system utilized only by the police force. Only the low estimates of benefits are analyzed.

6.4.2.1 Sensivity to Fleet Size. Because of the high cost of operating a police patrol car, attributable in large part to the salaries of the round-the-clock work force manning each car, single vehicle savings yield relatively higher benefits than in a corresponding case of a single bus saved. Thus, as shown in Figures VI-10A and VI-10B the total benefits are returned more quickly than total costs accrue. Costs and benefits on a per car basis show a rapid decrease

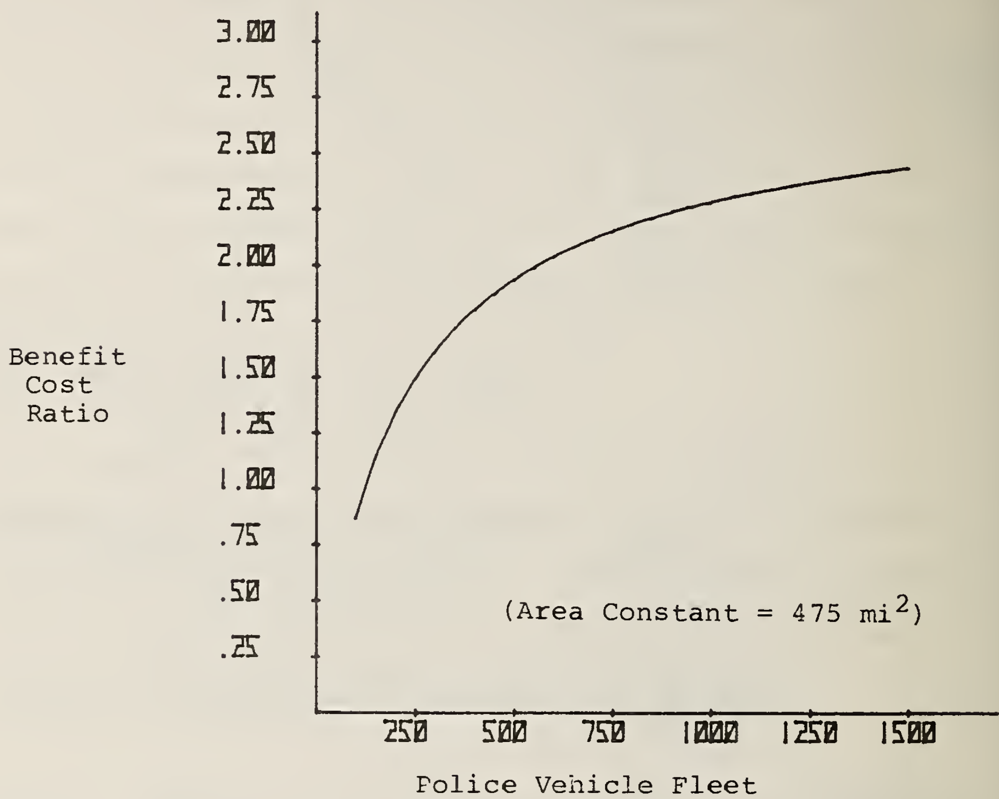


TOTAL BENEFITS & COSTS
FOR VARYING SIZES OF
POLICE FLEETS
FIGURE VI-10a
Present
Value
in
1975 Dollars x 10^3
(Discounted @ 10%)
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Total Benefits
Total Costs
250
500
750
1000
1250
1500
Police Fleet Size



BENEFITS & COSTS PER CAR FOR VARYING
SIZES OF POLICE FLEETS
FIGURE VI-10b
Present
Value
in
1975 Dollars
(Discounted @ 10%)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
Benefits Per Car
Costs Per Car
250
500
750
1000
1250
1500
Police Fleet Size

in expenditures per car against a constant benefit per car. The effect on the resultant benefit cost ratio is shown in Figure VI-11.



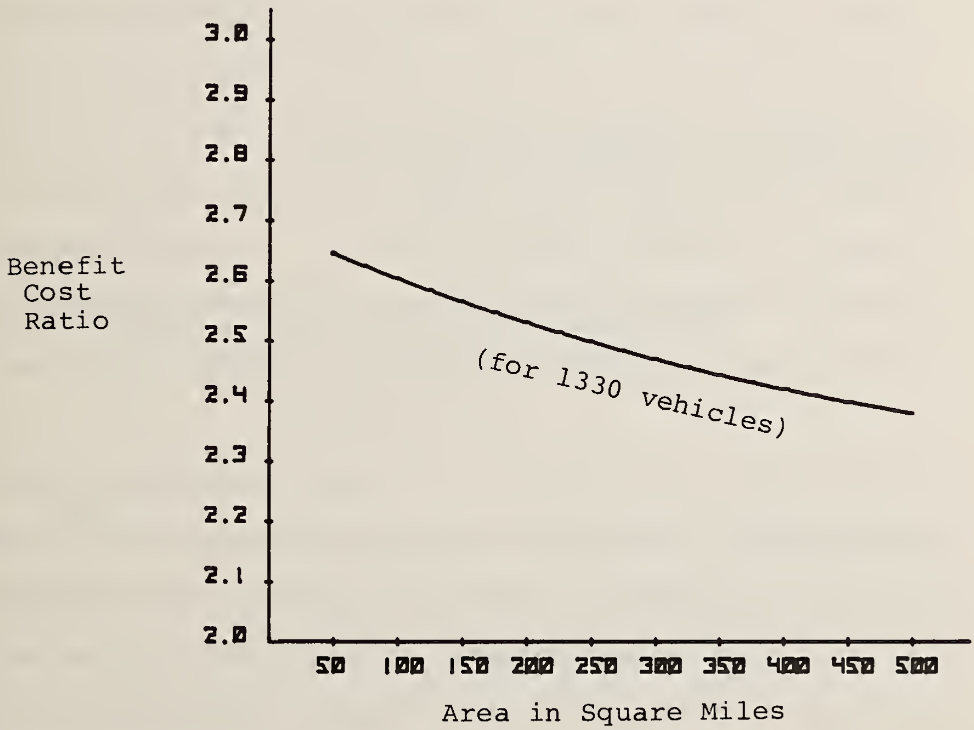
EFFECT ON BENEFIT COST RATIO FOR VARYING SIZES OF POLICE FLEET

FIGURE VI-11

Recall however, that these effects are derived for a constant area with a constant percentage reduction in time and miles due to AVM.

Within practical limits, this assumption yields realistic results that would be expected with an increasing density of cars within a given area.

6.4.2.2 Sensitivity to Area. Figure VI-12 illustrates the effect of decreasing the fleet density by increasing the area over which a fixed fleet is dispersed.



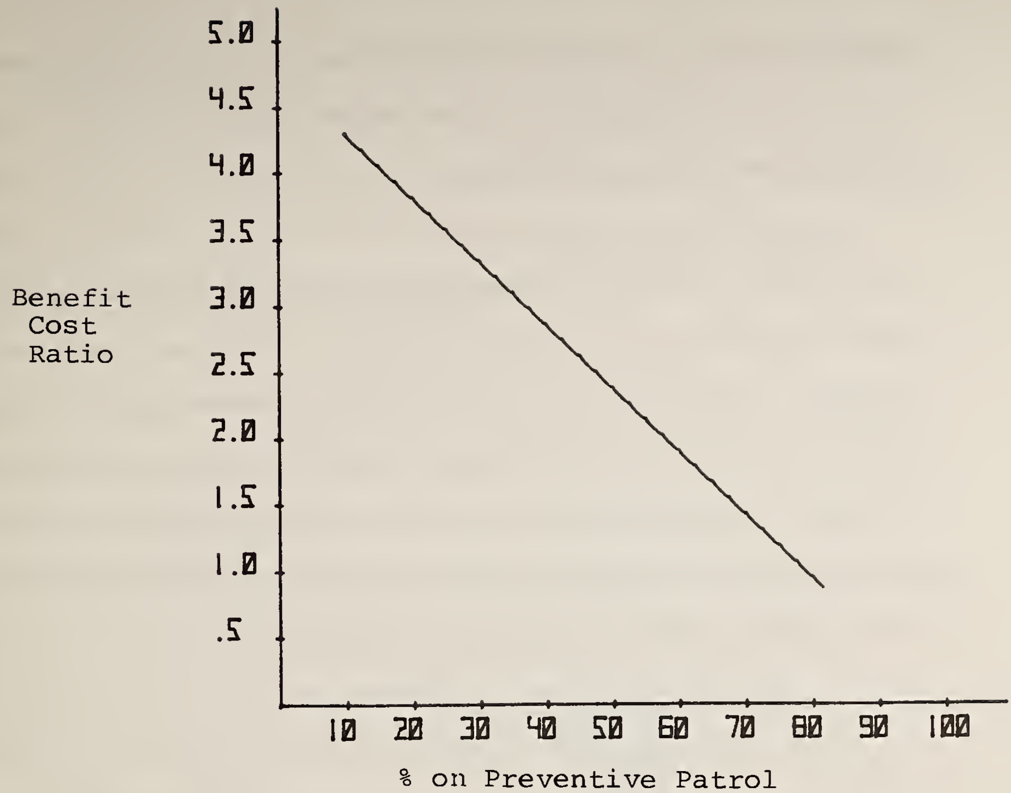
BENEFIT/COST RATIO FOR POLICE
AS A FUNCTION OF COVERAGE AREA

FIGURE VI-12

As can be seen the benefit cost ratio decreased as wayside equipment deployment costs increase. These results can lead to erroneous conclusions, since there are practical limits to the number of patrol cars per square mile, and no adjustment was incorporated to reflect the possibility of greater savings available in a low density operation. If this fact was taken into account, shrinkage of area around the base case would show decreasing benefits.

6.4.2.3 Sensitivity to Percent of Annual Miles Spent on Preventive Patrol. As the patrol area shrinks, it is realistic to believe that the fleet size would also decrease unless, of course, the number of vehicles involved in strictly preventive patrol went up. As this happens, the benefits that could be expected, in terms of miles saved would also be expected to decrease as shown in Figure VI-13.

Again, care must be taken in drawing conclusions from this information. In an extreme case where none of the annual mileage was spent on preventive patrol, the assumptions made in the model do not account for the fact that the position of each vehicle would then be known continuously by the dispatcher. AVM would furnish no additional position



EFFECT ON BENEFIT COST RATIO FOR POLICE
AS A FUNCTION OF PERCENTAGE OF TIME
SPENT ON PREVENTIVE PATROL

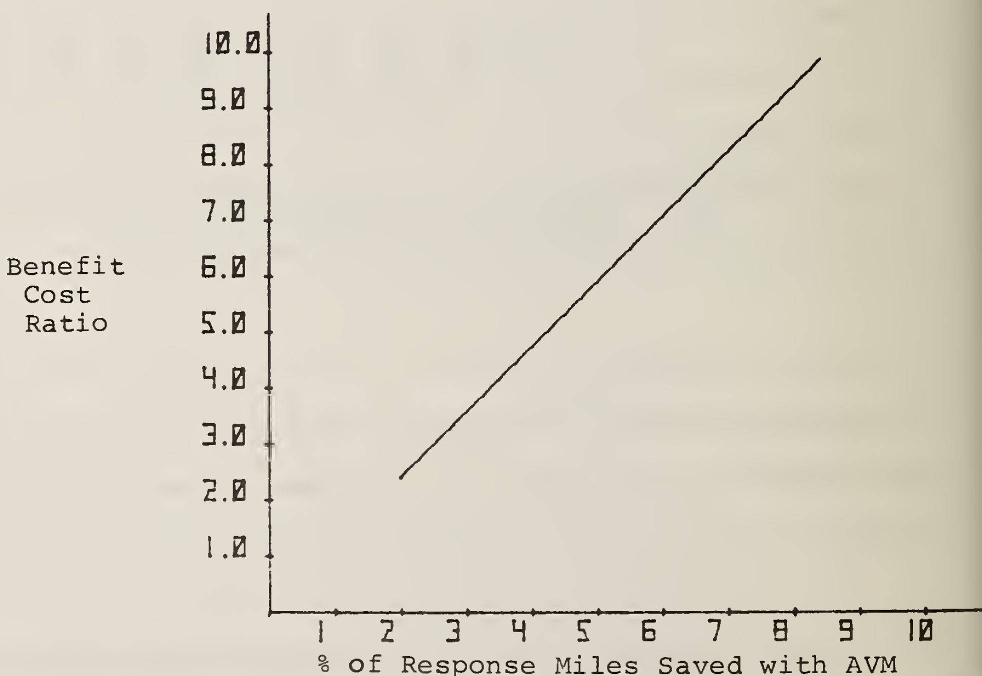
FIGURE VI-13

information, and the benefit in this case would be expected to disappear. Significant curtailment of available benefits occurs as this saturation point is approached.

6.4.2.4 Sensitivity to Expected Decrease in Response Time and Mileage. As the assumed savings thought possible through dispatching the single nearest vehicle to an

emergency are increased, the effect on the overall benefit cost ratio is dramatically positive. Figure VI-14 illustrates this situation.

As was just pointed out however, for a lesser percent of the fleet involved in preventive patrol, the resultant savings would be expected to increase up to a limiting value and drop off rapidly. A much more extensive analysis of this situation is suggested in order to determine the particular mix of police operations that would show the largest benefit for a given savings in time and mileage.

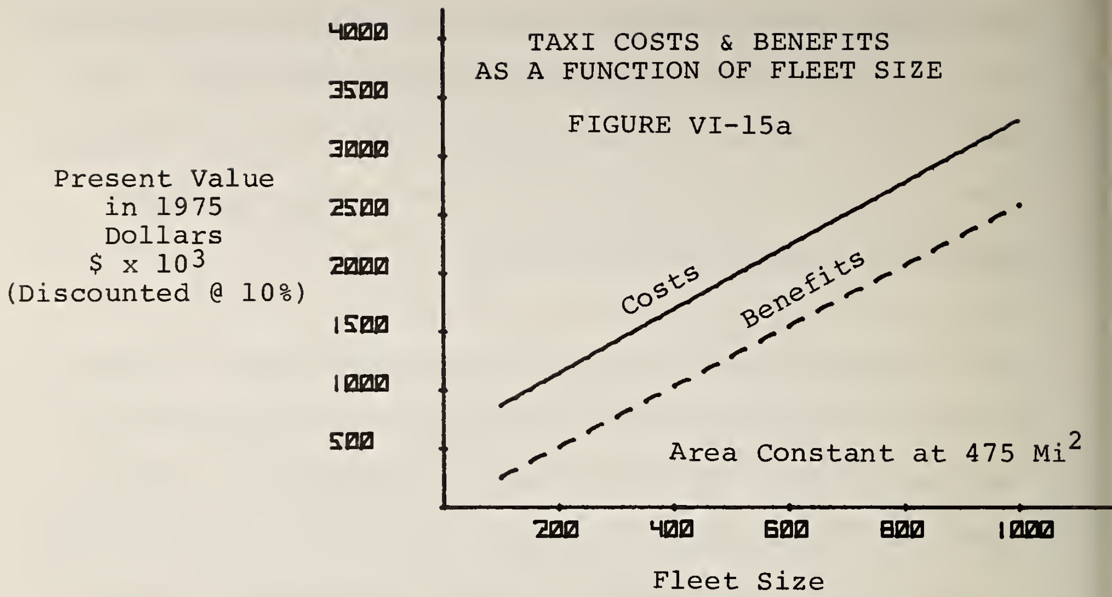


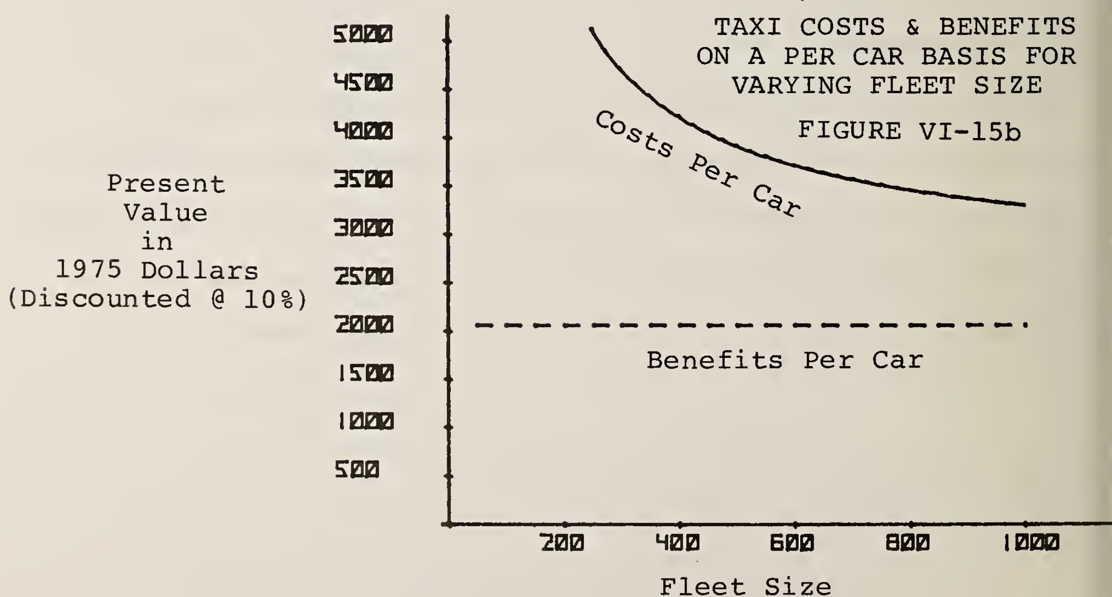
EFFECT ON BENEFIT/COST RATIO OF VARYING
RESPONSE MILEAGE SAVINGS

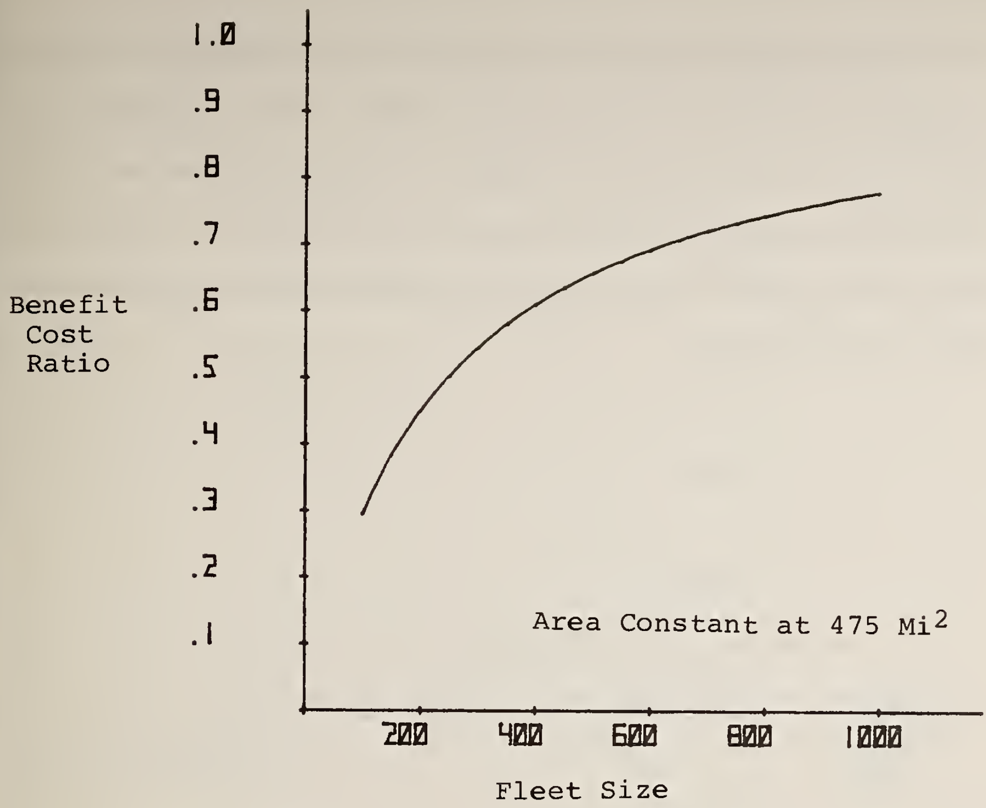
FIGURE VI-14

6.4.3 <u>Taxi</u>. The following figures are based on variations around the base fleet of 800 taxis operating within a 475 square mile area, with cost estimates for a radio frequency system utilized only by the taxi fleet. <u>Only the low estimates of benefits are analyzed</u>.

6.4.3.1 Sensitivity to Variations in Fleet Size. Though the taxi is a random route operation as is that of police, only the costs of the AVM system are comparable. Because the pay of drivers in a taxi system is based on commissions, any reduction in the number of drivers does not result in any significant payroll savings. Rather, the same percentage commission is merely divided by fewer drivers. Fixed vehicular operating costs and driver benefits are saved however. Thus, as is shown in Figure VI-15A, the benefits and costs assumed for the low case do not intersect. Accordingly, neither do the benefits and costs per car, as illustrated in Figure VI-15B. Thus, the overall benefit cost ratio shown in Figure VI-16, does not reach a breakeven point in the low case for a taxi operation.


TAXI COSTS & BENEFITS
AS A FUNCTION OF FLEET SIZE
FIGURE VI-15a
Present Value
in 1975
Dollars
$ x 10^3
(Discounted @ 10%)
4000
3500
3000
2500
2000
1500
1000
500
Costs
Benefits
Area Constant at 475 Mi^2
200
400
600
800
1000
Fleet Size


TAXI COSTS & BENEFITS
ON A PER CAR BASIS FOR
VARYING FLEET SIZE
FIGURE VI-15b
Present
Value
in
1975 Dollars
(Discounted @ 10%)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Costs Per Car
Benefits Per Car
200
400
600
800
1000
Fleet Size

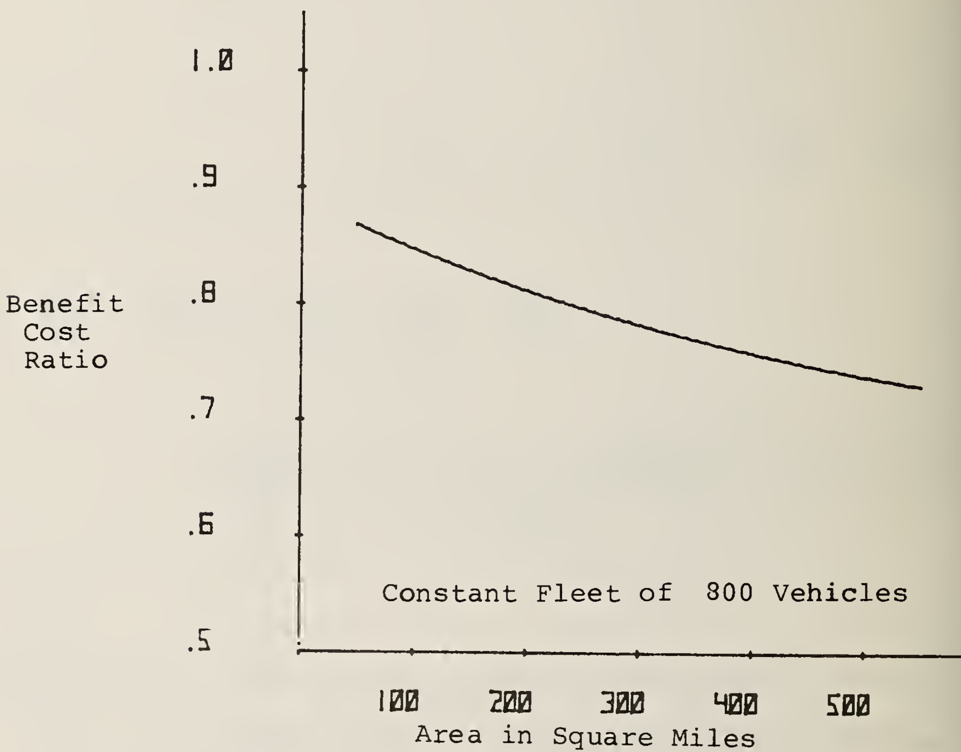


EFFECT ON TAXI BENEFIT-COST
RATIO FOR VARYING FLEET SIZES

FIGURE VI-16

6.4.3.2 Sensitivity to Variations in Area. For identical reasons as those given for the police case above, the benefit/cost ratio shows a decreasing relationship to increases in the size of the area covered. This relation does not decay as rapidly as for police as the unit benefits to be realized are less. However, it is also reasonable to expect that as the area of coverage decreases, fewer taxis

would be deployed as the total demand for service would be expected to shrink with area as well. Thus, Figure VI-17 should only be interpreted over a small range around the base case, to avoid the narrow conclusion that a fixed sized taxi fleet operation uniformly benefits when the service area is decreased.



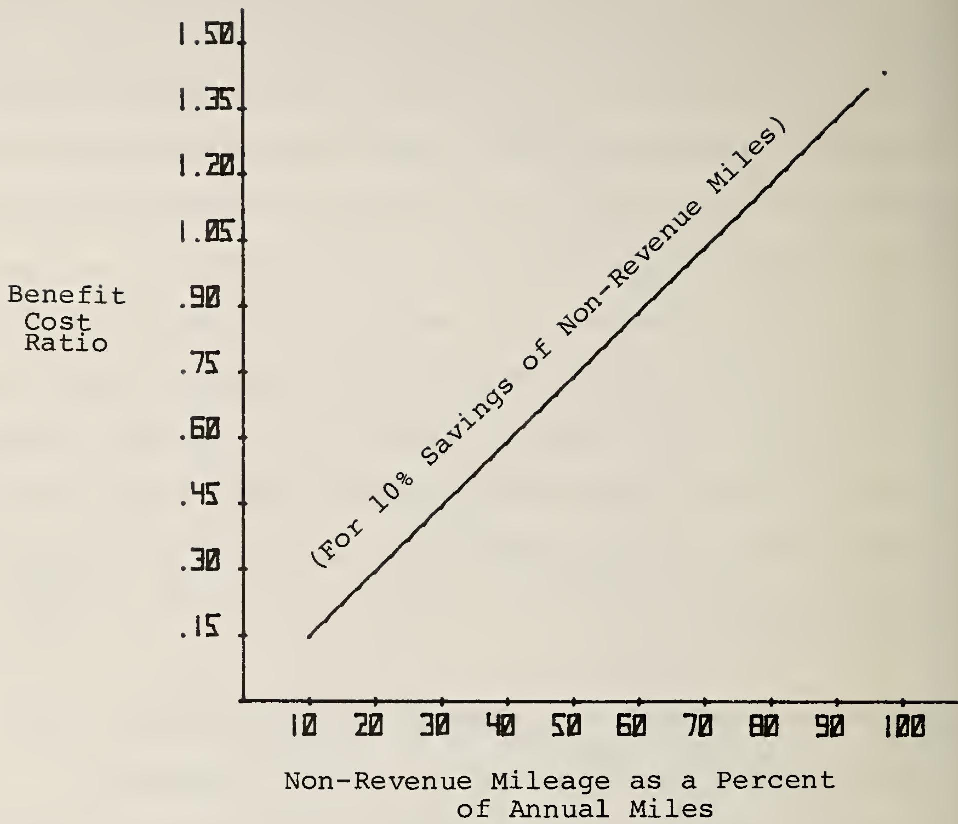
TAXI BENEFIT COST RATIO
SENSITIVITY TO
AREA OF COVERAGE

FIGURE VI-17

6.4.3.3 Sensitivity to Non-Productive Annual Mileage. Almost analogous to the police operation, wherein a portion

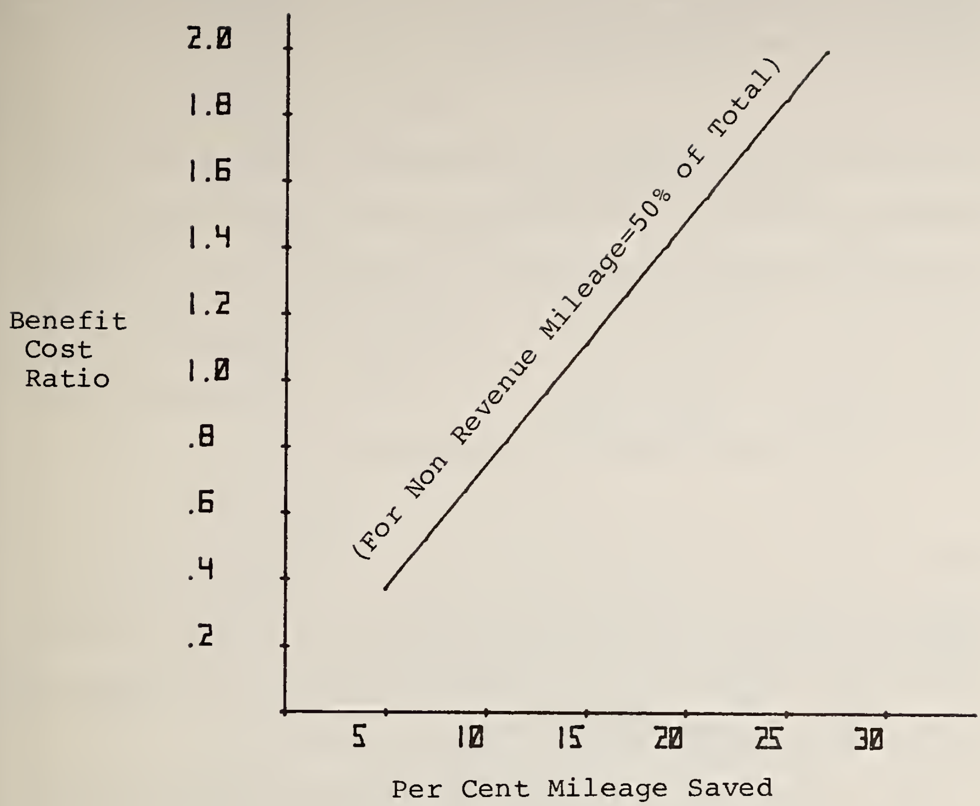
of the annual operating mileage is spent cruising on preventive patrol, a taxi accumulates non-revenue miles not only in cruising but in traveling to and from a fare, This non-revenue mileage is that which can be reduced through more effective dispatching. Thus expected savings from any percentage improvement are directly tied to the amount of non-revenue mileage generated. The relationship between this factor, assuming a 10% saving in such mileage, is shown in Figure VI-18. The expected savings reach a finite value at a point of 82%. This is because the base case assumes that 18% of the total mileage will be unavoidable as the next pickup point will seldom coincide with the previous drop off point.

6.4.3.4 Sensitivity to Expected Mileage Savings. Of course, as the assumption of the extent of savings achievable through nearest vehicle dispatching is changed, the benefits vary accordingly. The effect of varying this assumption from the base case value of 10% is shown in Figure VI-19.



SENSITIVITY OF BENEFIT/COST RATIO
TO TAXI NON-REVENUE MILEAGE

FIGURE VI-18



EFFECT OF TAXI MILEAGE
SAVINGS ON BENEFIT/COST RATIO

FIGURE VI-19

6.5 Multiple User Case Sensitivities

Variations in individual descriptors that forcibly hold interrelated variables constant tend to distort the true

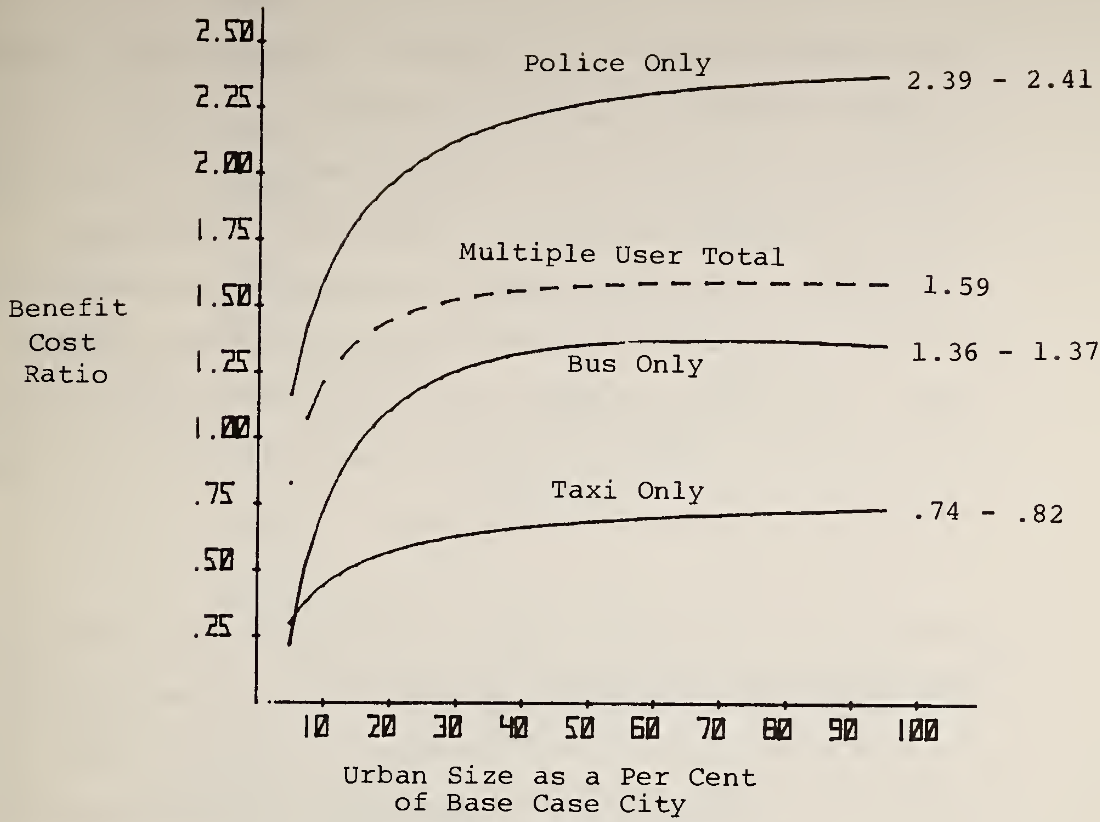
picture of what might be expected if a different site were chosen for AVM deployment.

As service areas expand or decrease, a matching of such changes to another representative urban area would undoubtedly show corresponding reductions in fleet sizes and operational characteristics. Even so, the highly individualized nature of todays urban areas would obviate all but the most vague of relationships.

This factor notwithstanding, it was felt necessary to develop a view of the possible effects of applying AVM in other urban areas. The following changes to the <u>base case</u> were used to describe other urban areas:

- The same percentage decrease in area would be applied to the total bus route miles, central core area and all operating fleet sizes.
- The number of field checkers would be decreased proportionate to changes in fleet size.
- The run times and layover times assumed for buses would be reduced exponentially.
- All other operating characteristics and cost factors as well as percentages used in all assumptions dealing with savings would be held constant.

Shown in Figure VI-20 is the expected trend in the low benefit cost ratio for varying sized urban cities <u>subject to the assumptions mentioned above</u>.



INDIVIDUAL AND MULTIPLE USER BENEFIT COST RATIOS AS A FUNCTION OF URBAN SIZE

FIGURE VI-20

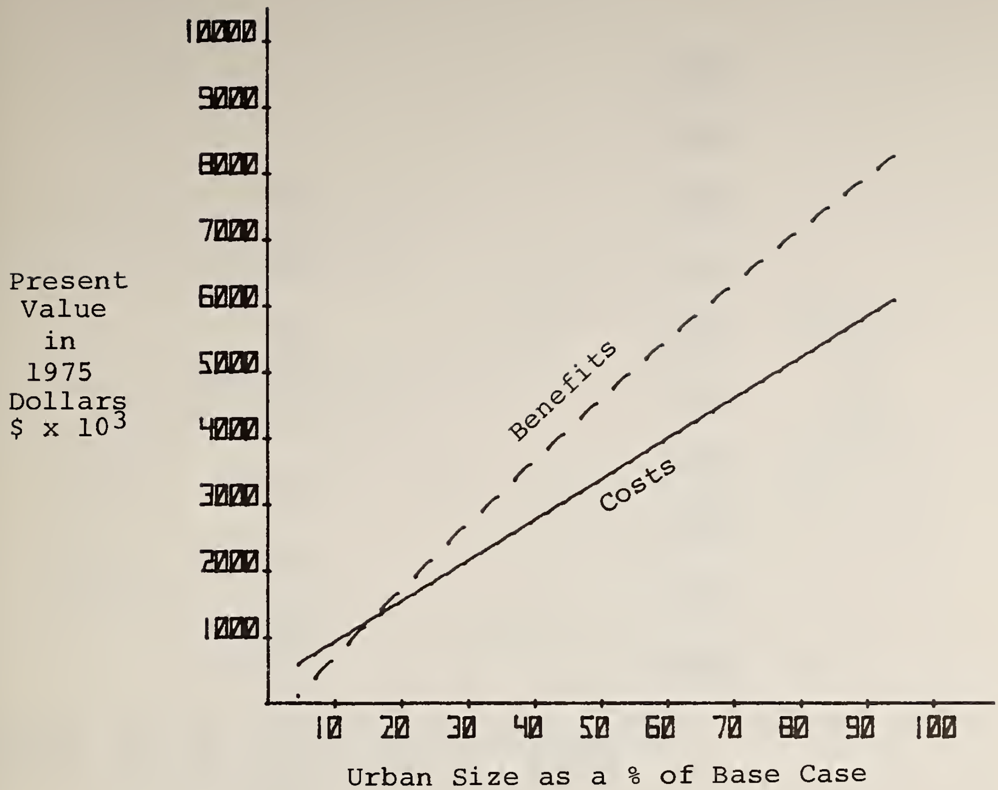
Individual user B/C ratios (low) are shown as solid lines and the B/C ratio that would be expected in a multiple user, cost sharing situation is shown as a dotted line.

The range of numbers shown at the terminus of each curve represents the maximum B/C value for individual operations and that expected by that user in a multi-user scenario.

Taxi operations were not analyzed in depth for this scenario as their financial operating structure is such that the low estimate of mileage-related savings apparently cannot exceed system implementation costs. Admittedly, while such limitations are readily subject to question, the extent of the implied analysis is beyond the scope of this current study. Additional emphasis was placed upon bus operations as it was felt that the possible impact would be of primary interest on fixed route operations.

Because the size of the field checker force was diminished with fleet size, the benefits within smaller bus operations are accounted for in a more realistic fashion. Thus, while benefits do exceed costs for most cases, urban sizes under 15-20% of the base case encountered costs which outweighed benefits as shown in Figure VI-21. Indications of the physical properties of the urban environment suggested by each percentage can be estimated from other characteristics of the base case city.

The total bus fleet of 2,400 vehicles operated over a system that provided 3,825 route miles of service. Thus a 50% urban situation would be represented by a system having 1,200 vehicles and operating 1,912 one way route miles.

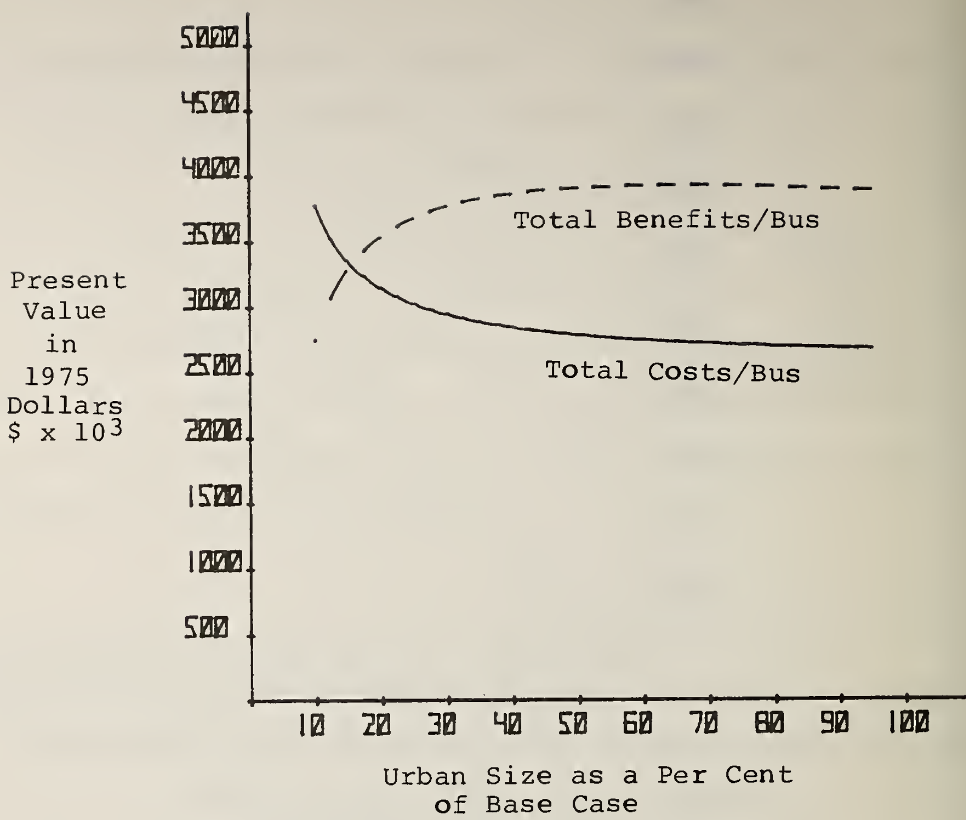


SYSTEM COSTS & TOTAL BENEFITS FOR
BUS OPERATIONS IN VARYING
URBAN SIZED AREAS

FIGURE VI-21

Hard conclusions as to the relationship of benefit/cost to city size should not be drawn from before such factors as the efficiency of operation and the extent of transit dependence by the population (unique for each service area) are considered.

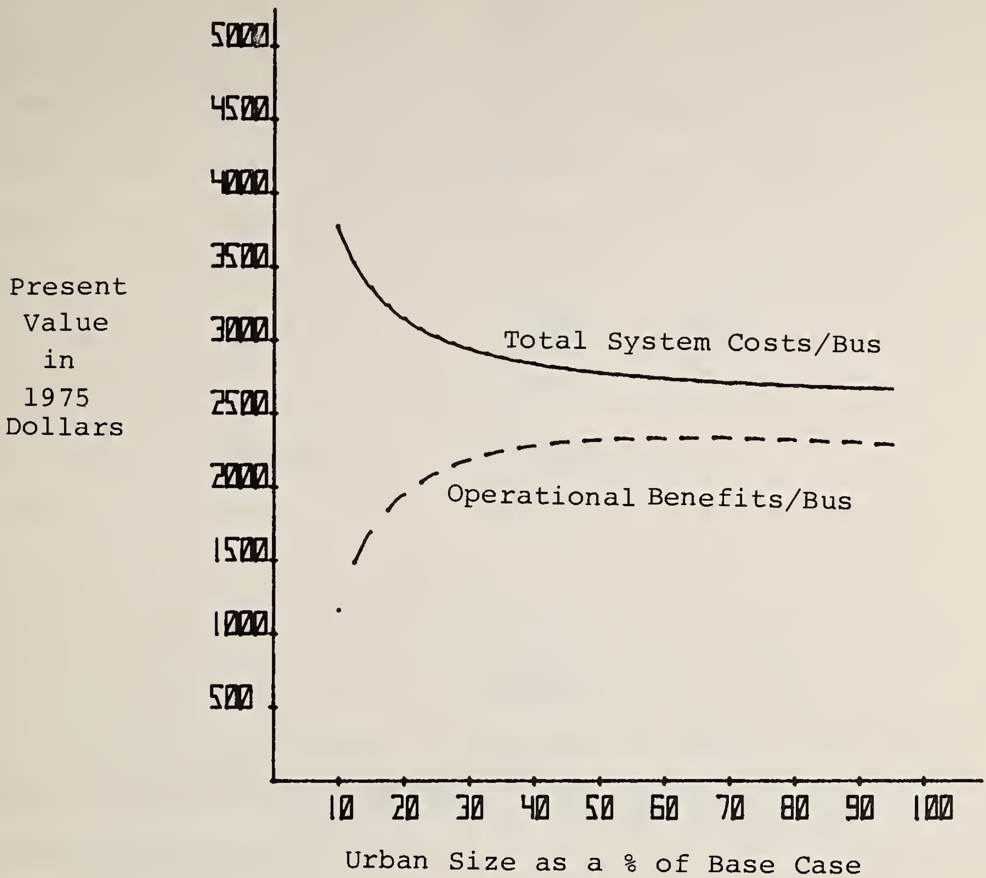
As can be seen in Figure VI-22, the costs per bus approach the $2,600 figure shown earlier for bus only operations.



TOTAL COSTS & BENEFITS PER BUS

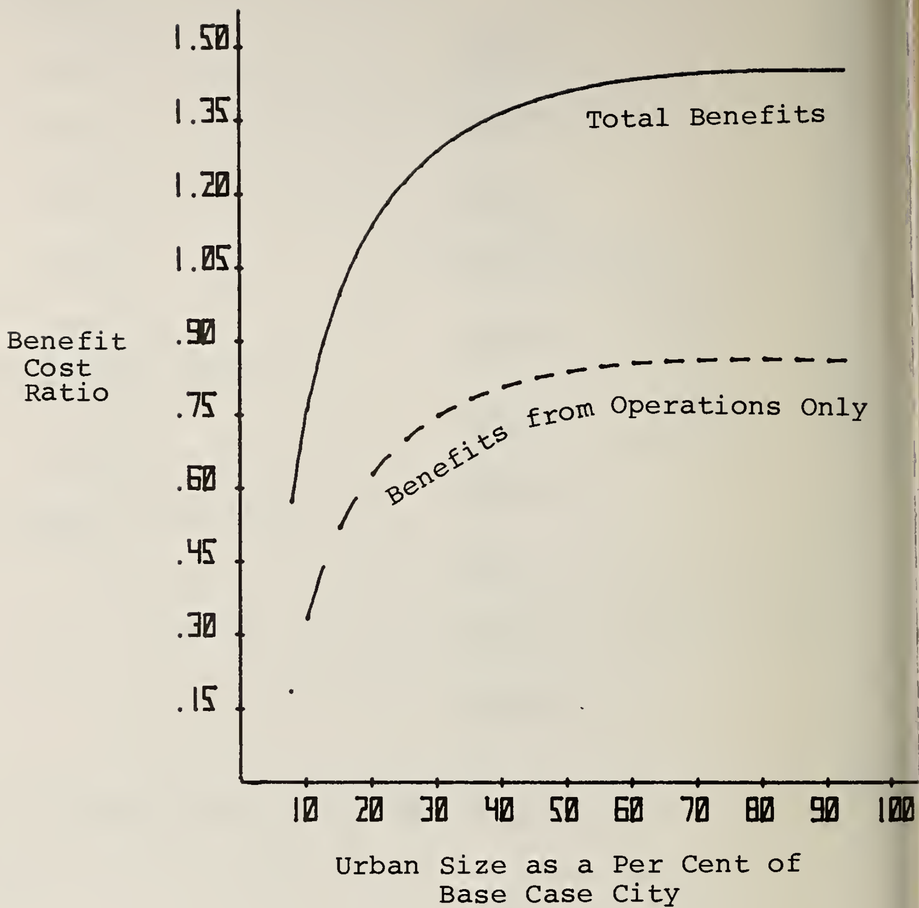
FIGURE VI-22

Note, however, that the total benefits still include savings from checkers and operations. Separating these results as shown in Fiqure VI-23, shows that operational benefits on a per bus basis never exceed the $2,600 value and result in the B/C ratios illustrated in Figure VI-24 which compares both total and operational benefits.



SYSTEM COSTS & OPERATIONAL BENEFITS
FOR VARYING URBAN SIZE AREAS

FIGURE VI-23



TOTAL & OPERATIONAL BENEFITS FOR
BUSES AS A FUNCTION OF URBAN SIZE

FIGURE VI-24

VII. SERVICE AND MANAGEMENT BENEFITS

7.1 Cost Reduction vs. Service Improvement

The prinicipal benefit of AVM is improved operating efficiency, which flows from continuous vehicle location information. The benefit-cost model captures efficiency improvements by holding the level of service constant while reducing fleet size and personnel strength. This approach yields a straightforward and confident estimate of the cost savings which can be achieved at a given level of effectiveness.

As indicated in Chapter III, cost reduction is only one of a wide range of strategies open to management for exploiting improved operating efficiency. The range of choice has been described as a continuum between two polar positions and illustrated as follows:

INCREASED EFFICIENCY. . .

REQUIRES A CHOICE BY
LOCAL POLICY-MAKERS. . .

IMPROVED SERVICE YIELDING PUBLIC BENEFITS	⟸ OR ⟹	CONSTANT SERVICE YIELDING OPERATING ECONOMIES

If managers elect to pursue a variation of the first goal, as have many in western Europe, analysts will be challenged to measure the benefits of improved service.

Improved service through AVM may mean reduced passenger wait times, more confident schedules, and shorter total trip time; operating efficiencies may be converted into more frequent trips and wider service provided by the same force of drivers and vehicles. Assigning dollar values to these benefits requires that ridership changes be projected from the service improvements. This cannot be done confidently because there is no generally accepted patron demand function or valuation of passenger wait and travel time. (For example, available estimates of the value of passenger wait and travel time vary by a multiple of four.) Faced with this difficulty, an analyst might choose to estimate the value of public benefits in terms of the avoidable cost of producing those benefits--that is, by measuring AVM cost savings, as has been done in this study.

7.2 Schedule Improvement

AVM, coupled with a reliable passenger counter, will produce a continuous record of bus demand data which can be grouped by route, stop, and time of day. As discussed in Chapter III, this data may be sampled or it may be measured in

totality. In either case, it is the raw material for developing and optimizing the total schedule, for readjusting routes and vehicle assignments to respond most effectively to overall demand, and thus to improve service. This benefit goes beyond the ability of AVM to help keep buses on schedule, beyond the layover and loadfactor improvements which grow out of that ability. It also goes beyond data collection savings which are achieved by automating the checker function. The schedule improvement benefit is defined as the long-term value of having good demand data in hand and using it regularly to adjust service to changing patterns of community needs and demands. The potential dollar value of this benefit depends upon the pre-AVM quality of each property's data collection, demand estimation, and schedule-making. This is difficult to specify in advance of AVM implementation and will vary greatly between properties, but it is clear that it is an important potential benefit. The schedule improvement benefit is not a factor in the base case due to the assumption that equipping 120 buses with passenger counters produces data comparable in value to the product of the current force of 60 manual checkers.

7.3 Security and the Silent Alarm

Exact location data from AVM offers important benefits when coupled with a silent alarm which permits the vehicle operator to transmit a digital code requesting emergency assistance without voice contact. This permits help to be directed to the exact point of need in the shortest time.

Insufficient data is available to make a confident dollar estimate of the value of the silent alarm. It is difficult to establish a causal connection between decreases in crime and a specific deterrent (such as AVM and the silent alarm) because criminal behavior is deeply rooted in a complex social environment. Even if this is accomplished, it remains difficult to find a widely accepted valuation of crimes against people, and even harder to project the ridership impact and general social value of increased feelings of personal security.

Despite these problems, the silent alarm appears to offer substantial benefits. For example, the Chicago Transit Authority found in a small sample that police response time to silent alarms was 38% faster for buses equipped with AVM than for buses equipped only with an alarm and no location indicator. It seems reasonable to agree with a modified

version of the argument for AVM and the silent alarm which was presented in Chapter II:

- AVM and a silent alarm should bring an increase in apprehension of taxi and transit criminals and vandals.
- Apprehensions plus publicity should lower transit crime and vandalism through deterrence. (However, transit crime and vandalism may be displaced to other targets.)
- Vehicle operator and police morale seem likely to increase so long as they have confidence in an AVM with silent alarm and "officer needs assistance" codes. This may reduce turnover and lost time and increase productivity.
- Public perceptions of greater safety may increase transit and taxi ridership, especially during night hours and in high crime neighborhoods.

These potential security benefits may be sufficient reason for decision-makers to proceed with an AVM implementation which appears marginal in terms of strict dollar benefits.

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APPENDIX A
BASE CASE DATA INPUTS

This appendix presents the operational and financial data used to calculate the base case benefits. Each entry lists the parameter, the base case value, and the source.

<u>BUS</u>

- Fleet Size

  2,400 vehicles. Southern California Rapid Transit District (SCRTD).

- Capital Cost Per Vehicle

  $64,000. TSC estimate.

- Vehicle Lifetime

  12 years. TSC estimate based on SCRTD data.

- Portion of Fleet Down for Maintenance

  16.53%. TSC analysis of SCRTD data.

- Portion of Fleet to be Equipped with Passenger Counters

  5%. TSC estimate.

- Area Coverage

  5,000 square miles. TSC analysis of SCRTD data.

* Number of Route Miles

  3,825. SCRTD estimate.

* Load Factor Improvement Due to AVM

  1% in the low case; 10% in the high case. TSC estimate.

* Portion of Buses on Short Headway Routes During Peak Hours

  50.07%. TSC analysis of SCRTD data.

* Platform Time

  81.8 minutes. TSC analysis of SCRTD data.

* Average One-Way Running Time

  68.2 minutes. TSC estimate based on SCRTD data.

* Average Layover Time

  13.67 minutes. TSC analysis of SCRTD data.

* Layover Improvement Due to AVM

  .93 minutes in the low case; 3.42 minutes in the high case. TSC estimate.

- Annual Insurance Cost per Vehicle

  $3,200. TSC estimate based on data provided by the American Public Transit Association (APTA).

- Annual Operation and Maintenance Cost per Vehicle

  $17,120. TSC estimate based on APTA data.

- Initial Checker Force

  60. SCRTD.

- Checkers to Remain with AVM

  20. TSC estimate.

- Portion of Periodic Maintenance Done According to the Calendar

  7.5%. TSC estimate.

- Attrition Rate

  10%. SCRTD estimate.

- Average Checker Salary

  $15,800. SCRTD estimate.

- Average Benefits and Overhead for Checker

  $15,800. TSC estimate.

- Initial Driver Force

  4,900. SCRTD estimate.

- Portion of Driver Payroll that is Overtime

  4.88%. TSC analysis of SCRTD data.

- Average Driver Salary

  $13,800. SCRTD estimate.

- Benefits and Overhead for Driver

  $3,100. TSC analysis of SCRTD data.

- Driver Pay Hours per Year

  2,284. TSC analysis of SCRTD data.

POLICE

- Fleet Size

  1,330 Patrol Cars. Los Angeles Police Department (LAPD).

- Vehicle Capital Cost

  $4,400. LAPD.

- Vehicle Lifetime

  3 years. LAPD estimate.

- Portion of Fleet Down for Maintenance

  20%. LAPD estimate.

- Area Coverage

  475 square miles. TSC estimate based on Los Angeles data.

- Annual Miles per Car

  27,000. LAPD estimate.

- Portion of Miles Spent in Preventive Patrol

  50%. TSC estimate.

- Reduction in Response-to-Call Mileage Due to AVM

  2% in low case; 10% in high case. TSC estimate.

- Operation and Maintenance Cost per Mile

  $.183. LAPD estimate.

* Annual Insurance Cost per Car

    $0. LAPD.

* Patrolmen per Vehicle

    3.3. LAPD estimate.

* Average Patrolman's Salary

    $21,800. LAPD estimate.

* Average Annual Benefits and Overhead for Patrolmen

    $21,800. TSC estimate.

* Attrition Rate

    10%. TSC estimate.

<u>TAXI</u>

* Fleet Size

    800 cabs. Yellow Cab Company of Los Angeles.

* Vehicle Capital Cost

    $3,000. Estimate.

• Vehicle Lifetime

3 years. Estimate.

• Area Coverage

475 square miles. TSC estimate based on Los Angeles data.

• Average Annual Mileage per Cab

50,000. Estimate.

• Portion of Mileage that is Non-Revenue

50%. TSC estimate.

• Portion of Mileage that is Unavoidable Non-Revenue

18%. TSC estimate.

• Portion of Avoidable Deadheading Saved Due to AVM

10% in the low case; 20% in the high case. TSC estimate.

• Operation and Maintenance Cost per Mile

$.093. TSC analysis of data in Paratransit, by R.F. Kirby, et al.

• Annual Insurance Cost per Vehicle

$1475. TSC analysis of data in Paratransit.

- Drivers per Vehicle

  2.1. TSC estimate.

- Drivers on Salary

  0.

- Annual Non-Salary Benefits per Driver

  $1,350. TSC estimate based on YLCA data.

- Attrition Rate of Taxi Drivers

  33%. TSC estimate.

<u>AVM COST FACTORS</u>

Costs for AVM equipment are drawn from "Automatic Vehicle Monitoring System Deployment Costs," by Bernard E. Blood, TSC AVM Document 5.1.3. and memo from TSC AVM project Office entitled, "Additional Information - AVM System Deployment Costs," listing percentage cost variations for generic systems.

SHARP SIGNPOST

• On-Vehicle Equipment	
Location Subsystem	
Fixed Route	$ 2,950 per vehicle
Random Route	$ 3,250 per vehicle
Passenger Counter	$ 550 each
• Wayside Equipment	
Signposts (6 per route mile, 148 per square mile)	$ 40 each
Remote Receivers (1 per 127 route miles, 1 per 127 square miles)	$ 10,000 each
• Central Equipment	
Basic Communication	$ 20,000
Variable Communication	$ 1,000 per 250 vehicles
Basic Data Processing	$188,000
Variable Data Processing	$ 62,000 per 250 vehicles
• Total Cost Variation	±20%

BROAD SIGNPOST

• On-Vehicle Equipment	
Location Subsystem	$ 1,150 per vehicle
Passenger Counter	$ 550 per vehicle
• Wayside Equipment	
Signposts (1 per mile, 37 per square mile)	$ 74 each
Remote Receivers (1 per 210 route miles or square miles)	$ 8,000 each
• Central Equipment	
Basic Communication	$ 15,000
Variable Communication	$ 1,000 per 250 vehicles
Basic Data Processing	$160,000
Variable Data Processing	
Fixed Route	$ 39,000 per 250 vehicles
Random Route	$ 23,000 per 250 vehicles
• Total Cost Variation	±5%

RADIO FREQUENCY

• On-Vehicle Equipment	
Location Subsystem	$ 1,600 per vehicle
Passenger Counter	$ 550 each
• Wayside Equipment	
Signposts (Signal Boosters) (1.25 per mile, 2.16 per square mile)	$ 216 each
Remote Receivers (1 per 260 miles or square miles)	$ 8,000 each
• Central Equipment	
Basic Communication	$ 10,000
Variable Communication	$ 1,000 per 250 vehicles
Basic Data Processing	
Fixed Route	$152,000
Random Route	$120,000
Variable Data Processing	$ 13,000 per 250 vehicles
• Total Cost Variation	±18%

DEAD-RECKONING

- On-Vehicle Equipment

Location Subsystem	
Fixed Route	$ 4,040 per vehicle
Random Route	$ 4,000 per vehicle
Passenger Counter	$ 550 each

- Wayside Equipment

Mapping Cost	
(1 per mile or square mile)	$ 180
Remote Receivers	
(1 per 41 miles or square miles)	$ 14,000

- Central Equipment

Basic Communication		
Fixed Route	$ 29,000	
Random Route	0	
Variable Communication		
Fixed Route	$ 8,500	per 500 vehicles
Random Route	$ 40,000	per 500 vehicles
Basic Data Processing		
Fixed Route	$264,000	
Random Route	$204,000	
Variable Data Processing		
Fixed Route	$109,000	per 250 vehicles
Random Route	$159,000	per 250 vehicles

- Total Cost Variation $\pm$6-1/2%

APPENDIX B

USER'S MANUAL FOR

BENEFIT COST MODEL

This appendix describes the inputs to be used during a run of the Benefit-Cost computer program, and is intended to bridge the gap between the descriptive material in the main text, and the detail program flow diagrams of the model that follows. It should be read before preparing input data.

A simplified format is used that lists data items (in their internal neumonics) to be input in the left hand column, with a description of procedures (and capitalized data titles) to the right of those variables. In this way, a quick perusal for a given fleet will give the order of entry of data items.

The program, written in Fortran IV, has two main programs, AVMPR and BENFT. The sub-programs called by each are:

Name	Blocks	Name	Blocks
AVMPR:	29	BENFT:	29
TELCO	1	BUSBN	21
DSUM	1	POLBN	9
		TAXBN	16
		DIABN	11
		VRAT	1
		CAPSV	2
		PATRT	4
		LOSS	9
TOTAL	31		102

The object programs are stored on disk at TSC and run on a PDP-KL-10. A block is defined as 600 characters. When compiled, the executable code for the cost program occupies 29 blocks and the benefit program 72.

The following functions are used to translate actual dollar values into 1975 dollars:

1. The Present Value Function

   $PV(C) = [C(1-(1+rate)^{NYR}]/rate$

2. Present Value of a Future Annuity Function

   $PVFA(Y) = Y[1-(1+rate)^{NPER-n+1}]/(1+rate)$

3. Present Value of a Future Sum

   $PVFS(Y) = {}^{Y}/(1-rate)^{-N}$

where:

RATE is the DISCOUNT RATE

NYR is the AVM SYSTEM LIFE

NPER is the NUMBER OF PERIODS

N is the NUMBER OF YEARS

COST CALCULATIONS

Each execution of the COST PROGRAM passes through the computational steps of the model four times, to provide Implementation cost figures for each of the generic AVM system technologies embodied in the Program. Representative cost factors for on-vehicle equipment, wayside equipment, and central equipment for each system are assessed for each fleet entered.

The model is designed for fleets that either travel on routes, or those in random service areas, and will also assess costs for an AVM system shared by up to six users. In beginning the Cost run, the first two input

AREA — variables determine wayside equipment costs for the total area shared by all users. AREA consists of the combined areas, expressed in square miles, to be served by participating fleets, including the entire area served by buses, which is bounded by an imaginary line connecting the ends of bus

PXLMT — routes extending outward from the core service area. TERRAIN DESCRIPTION adjusts that number of remote receivers required, to compensate for irregular obstructions that may interfere with signal transmission.

USER — The variables that follow regard individual fleets. Care must be taken in inputting TYPE OF FLEET, to type the word naming the fleet (e.g., BUS, TAXI, POLICE, DIAL-A-RIDE, EMERGENCY, etc.) first, with no blanks to the left (left adjusted). In the Benefit Program, separate subroutines have been written for BUS, POLICE, TAXI, and DIAL-A-RIDE fleets, and fleets so named must be left adjusted in the same manner, or they will be recognized

as a generalized fleet by the computer, thus by-passing specific fleet-
NVEH related COST and BENEFIT items. The NUMBER OF VEHICLES is next input.
KCTR For bus fleets, this will be followed by the PERCENT OF FLEET TO BE EQUIPPED
SQ. MILES WITH PASSENGER COUNTERS. Inputs concerning the number of SQUARE MILES or
RTE. MILES ROUTE MILES involve only those used by the fleet being costed. (Normally, bus fleets would travel on fixed-routes only with no "square mile" coverage, and random route fleets would require square mile coverage only, with no "fixed-route" coverage.)

After data for all fleets are entered, costs for a multiple user, shared
TOTAL AVM system are calculated by typing TOTAL (left adjusted) in response to
SQ. MILES TYPE OF FLEET, and then inputting the number of SQUARE MILES, covered by
RTE. MILES random route users shared or non-shared, and any ROUTE MILES that are not included within the "square miles" used by fixed-route users. Running totals of unshared on-vehicle and unshared incremental central equipment costs are maintained, and new costs for shared wayside and shared basic central equipment are calculated, based on the total shared service area data.

COST SHARES

All inputs for the cost sharing portion of the conversation are either YES or NO or a number. All equipment that is not on a per-vehicle basis, i.e., wayside and basic central equipment, is assumed shared if there is

more than one AVM user in an area. Central Communication and Data Processing Cost shares are calculated according to the number of vehicles in one fleet, in relation to the number of vehicles in all fleets. Wayside cost shares for fleets in more than one area can be apportioned

MTHD in one of two ways, based on conversation concerning METHOD OF APPORTIONMENT. Inputting the number 1 will apportion vehicles according to the number of route miles in that area in proportion to total route miles traveled by that fleet.

(query) To complete the inputs for the cost sharing program, it is necessary to confirm the number of users that share a particular service area, the size of the shared area, and the particular fleets involved. Conversation will continue until all area input during the TOTAL multiple-user is accounted for. The output will compare single user costs against cost-shares for each fleet.

BENEFIT CALCULATIONS

The Benefit Program is entered upon command, with computer conversation based on the previously-run Cost Program. Separate subroutines are called for BUS, POLICE, TAXI, and DIAL-A-RIDE fleets, all others entering a general procedure. Default Values, reflecting data collected for the base case, are used when no specific value is stated for variable inputs that have been incorporated in the individual algorithms (see Appendix A). If a default has been stated, but a value of 0 is preferred, the operator must use a small, but finite, number (i.e., 0.00001) instead of 0 or carriage return to avoid the default value from being used.

In all cases, Capital and Operations and Maintenance Savings are calculated based on vehicles saved. The subroutine CAPSV returns the present value of capital costs avoided based on the vehicle life and costs. Personnel reductions consist of drivers saved and other administrative personnel. Driver Savings are calculated in relation to vehicles saved. The Bus Case additionally considers the administrative cost of data gathering personnel. The General Case allows for either proportional personnel reduction, or an input number to be attrited.

The mode-specific subprograms allow unique benefits to be calculated for fleets. The Taxi algorithm contains an option for savings due to high-flag reduction. As most bus operations employ a staff of checkers used for evaluation of passenger loadings and subsequent schedule revision, benefits that accrue from a reduction in this force are calculated.

Any additional costs for training and increased salaries, and additional personnel are calculated for each fleet, based on conversation at the end of the subroutine. The additional expenses are added to the total single and multiple user costs, before the benefit-cost ratios are calculated.

BENEFIT INPUTS

Vehicle Savings

BUS	POL	TAXI	DIA	GEN	Capital
					Each subroutine requires estimates of savings due to AVM economies. The BUS fleet derives its savings from
PCNT (LO) (HI)					LOAD FACTOR IMPROVEMENT, input as LOW and HIGH percentage estimates, and layover reductions where average one-way
RTIME					RUN TIME and the percentage estimate of the BUS FLEET
FHDWY					EMPLOYED ON ROUTES WITH HEADWAYS OF LESS THAN 10 MINUTES is input,
ALAY RLAY (LO) (HI)					followed by CURRENT LAYOVER in minutes, and and future LAYOVER GOALS, (LOW and HIGH). Vehicle savings for POLICE fleets result from a reduction in response
	PPP				time mileage. A percentage relating MILEAGE SPENT IN PREVENTIVE PATROL to total miles traveled is first input,
	RPS (LO) (HI)				followed by LOW and HIGH percentage estimates of RESPONSE MILEAGE SAVINGS.
					TAXI vehicle savings derive from reductions in mileage spent traveling in response to calls for service. Inputs
		PPP			in this area include the PERCENTAGE OF TOTAL MILEAGE THAT
		UDHP			IS UNPRODUCTIVE, the PERCENTAGE THAT IS UNAVOIDABLE
		PVM			DEADHEAD, and an estimate of ANNUAL MILEAGE TRAVELED PER
		RPS (LO) (HI)			VEHICLE. Low and High estimates of the REDUCTION IN AVOIDABLE DEADHEAD MILEAGE are then input.

BUS	POL	TAXI	DIA	GEN	
		HFP (LO) (HI)			The subroutine will enter a loop (upon request) to estimate costs and savings for equipment to prevent high-flagging. The first input after the "YES" response to the high-flag interrogation is the expected % REVENUE INCREASE due to the anti-high-flag equipment. If the net value of the additional equipment is negative in both the high and low cases, confirmation will be required to include these additional equipment costs and benefits in the analysis.
			PAX XMIN PAUS		DIAL-A-RIDE savings derive from increasing the efficiency of vehicles, by allowing for notification (cost of providing this notification is described later) of vehicle arrival and thereby reducing the amount of dwell time vehicles encounter waiting for passengers to board. PASSENGERS SERVED PER HOUR is first input, followed by current DWELL TIME PER STOP, and HIGH and LOW GOALS FOR REDUCTION IN DWELL TIME (in minutes).
				PVS (LO) (HI) XCC XLF	For the GENERAL procedure, an estimate must be provided for LOW and HIGH VEHICLE SAVINGS due to AVM. COST OF A NEW VEHICLE less salvage value, followed by EXPECTED VEHICLE LIFE is then entered.

BUS	POL	TAXI	DIA	GEN	
					<u>Vehicle Savings</u>
BUS	POL	TAXI	DIA	GEN	<u>Operation & Maintenance</u>
VIC	VIC	VIC	VIC	VIC	O&M and Insurance Savings are calculated next, based on inputs. ANNUAL INSURANCE COSTS are entered, followed by
VOM	VOM	VOM	VOM	VOM	ANNUAL OPERATION AND MAINTENANCE COSTS. The BUS subroutine calls for an estimate (in dollars, if the default
PRMNT					is not used) of the PORTION OF MAINTENANCE COSTS USED FOR PERIODICS, (i.e., maintenance performed according to the calendar for each vehicle).
					In order to provide notification of vehicle arrival to passengers, a staff of telephone operators must be added to place phone calls to alert passengers to the imminent arrival of the vehicle. Inputs to calculate the additional
			CALLS CSAL CBEN		costs include CALLS PER CALLER PER HOUR, ANNUAL SALARY PER CALLER, and ANNUAL BENEFITS AND OVERHEAD PER CALLER.
					Further savings for BUS fleets will result from a reduction
FORCE					in the number of checkers in the labor force. The CURRENT
REM					CHECKER FORCE and the NUMBER OF CHECKERS TO REMAIN IN THE DEPARTMENT (after AVM implementation) are then entered,
SAL BEN ARATE					followed by SALARY PER CHECKER, BENEFITS PER CHECKER, and the checker ATTRITION RATE.

BUS	POL	TAXI	DIA	GEN	Personnel Savings
PPV FORCE SAL BEN ARATE	PPV FORCE SAL BEN ARATE	PPV FORCE SAL BEN ARATE	PPV FORCE SAL BEN ARATE	PERS (LO) (HI)	Personnel savings for each fleet are calculated in direct proportion to vehicles saved (slight variation for bus described below). Variables input to perform this calculation are PERSONS PER VEHICLE, TOTAL FORCE, ANNUAL SALARY and BENEFITS, and the DRIVER ATTRITION RATE. In the GENERAL Procedure, an option is available to calculate personnel savings by directly inputting the number of people saved, rather than a number proportionate to vehicle savings.
OTIME AHRS					Personnel Savings in the BUS algorithm derive first from a reduction in OVERTIME HOURS, input as a portion of TOTAL DRIVER HOURS PAID, the next input.
S F E	S F E	S F E	S F E	S F E	Each subroutine enters the subroutine LOSS to add start-up costs for an AVM system. After responding "YES" to conversation concerning any additional implementation costs, the first input concerns INSTALLATION COSTS PER VEHICLE, followed by any FIXED COST for central equipment (i.e., general purpose computer, switchboards) not included in the COST PROGRAM. Costs of any AUXILIARY EQUIPMENT required to obtain the benefits claimed are then entered, and are calculated; a 10% maintenance cost is added.

BUS	POL	TAXI	DIA	GEN	
APERS	APERS	APERS	APERS	APERS	The number of any ADDITIONAL PERSONNEL TO BE ADDED (i.e., dispatchers, callers) are entered next, followed by estimates of ANNUAL SALARY AND BENEFITS PER PERSON ADDED.
ASAL ABEN	ASAL ABEN	ASAL ABEN	ASAL ABEN	ASAL ABEN	
UPERS	UPERS	UPERS	UPERS	UPERS	Additional costs for salaries of personnel whose position might be upgraded to operate AVM are calculated for the 10-year expected system life upon input of the NUMBER OF PERSONNEL AFFECTED, and the AVERAGE ADDITIONAL SALARY PER YEAR.
USAL	USAL	USAL	USAL	USAL	
PT	PT	PT	PT	PT	Inputs concerning training costs follow. The NUMBER TO BE TRAINED is entered first, followed by the NUMBER OF HOURS OF TRAINING PER PERSON required, and the COST PER PERSON. Any ADDITIONAL TRAINING COSTS (i.e., for materials of instructors) is then input.
H	H	H	H	H	
XI	XI	XI	XI	XI	

COST PROGRAM VARIABLES

HARDWARE COST VARIABLES

CLS: Per-Vehicle Location Subsystem Cost for Fixed-Route Fleet

CLS2: Per-Vehicle Location Subsystem Cost for Random-Route Fleet

CSP: Unit Cost for Site Preparations

YSP1: Spacing of Site Preparations on a Fixed-Route

YSP2: Spacing of Site Preparations in Area Coverage

CRR: Cost per Remote Receiver

PX: Placement of Remote Receivers

BCOM: Basic Communications Cost

ECOM: Variable Communication Cost

CDP1: Basic Data Processing Cost for Fixed-Route Fleets

CDP2: Basic Data Processing Cost for Random-Route Fleets

CEDP1: Variable Data Processing Costs for Fixed-Route Fleets

CEDP2: Variable Data Processing Costs for Random-Route Fleets

RATE: Annual Discount Rate

NYR: AVM System Life

NRR: Number of Remote Receivers Required

NSP: Number of Signposts Required

Technology (I):

1. Sharp Signpost
2. Broad Signpost
3. Radio Frequency
4. Dead Reckoning

DEPLOYMENT VARIABLES

AREA: Total Service Area

PXMLT: Adjustment of Remote Receiver Placement According to Terrain

NVEH: Number of Vehicles in Fleet

KCTR: Portion of Bus Fleet to be Equipped with Passenger Counters

KRAD: Adjustment for Additional Voice-Radio Costs

NSR: Number of Fleets Sharing Service Area

DIST: Number of Miles or Square Miles Shared

INTERMEDIATE VARIABLES

BAL:	Running Total of Remaining Shared Area
FACTOR:	Multiplier Dependent on Area Shared
XDENOM:	Variable Denominator Used in Assessing Cost Shares for Wayside Equipment
DENOM:	Variable Denominator Used in Assessing Cost Shares for Central Equipment
CRSP:	Share of Signposts on Routes
CASP:	Share of Signposts in Mutual Random Service Area

PRINT:

FOR (USER)

Capital Costs	
On-Vehicle Equipment	TLS(I)
Signposts	TSP(I)
Remote Receivers	TRR(I)
Communications	
Basic	BCOM(I)
Variable	ECOM(I)
Data Processing	
Basic	BDP(I)
Variable	EDP(I)
Fleet Total	
Annual Maintenance Costs	
On-Vehicle Equipment	TLSM(I)
Signposts	TSPM(I)
Remote Receivers	TRRM(I)
Communications	
Basic	BCMM(I)
Variable	ECMM(I)
Data Processing	
Basic	BDPM(I)
Variable	EDPM(I)
Total Annual Maintenance	TOTM(I)
PV Annual Maintenance	PVTM(I)
PV Total Cost	PVCOST(I)

PRINT:

COMPARISON OF COSTS

FOR (USER)

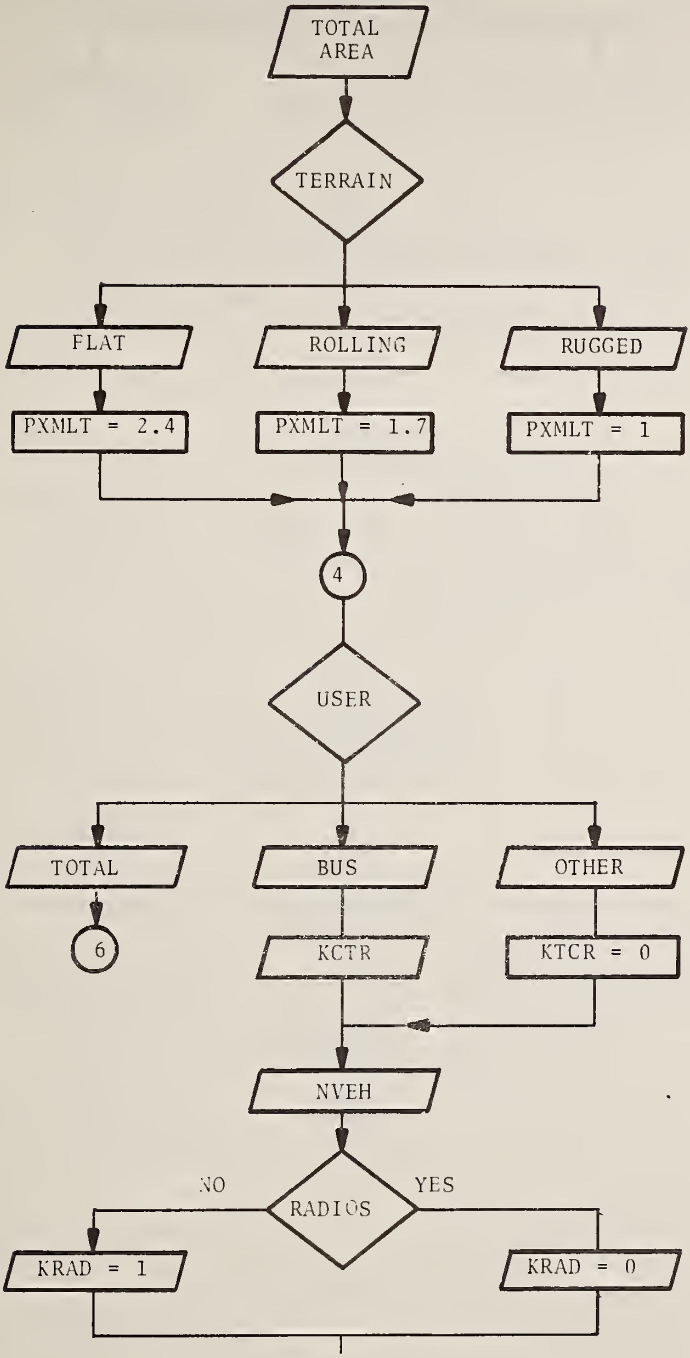
	Alone (Tech)	Share of Multi-User (Tech)
Capital Costs		
On-Vehicle Equipment	TLS(LOW)	TLS(LOW, SHARED TECHNOL
Signposts	TSP(LOW)	SHRSP
Remote Receivers	TRR(LOW)	SHRRR
Communications		
Basic	BCOM(LOW)	SHRBC
Variable	ECOM(LOW)	ECOM(SHARED)
Data Processing		
Basic	BDP(LOW)	SHRDP
Variable	EDP(LOW)	EDP(SHARED)
Fleet Total	TOT(LOW)	TOT(SHARED)
Annual Maintenance Costs		
On-Vehicle Equipment	TLSM(LOW)	TLSM(SHARED)
Signposts	TSPM(LOW)	SHRSPM
Remote Receivers	TRRM(LOW)	SHRRRM
Communications		
Basic	BCMM(LOW)	SHRBCM
Variable	ECMM(LOW)	ECMM(SHARED)
Data Processing		
Basic	BDPM(LOW)	SHRDPM
Variable	EDPM(LOW)	EDPM(SHARED)
Total Annual Maintenance	TOTM(LOW)	TOTM(SHARED)
Project Value Total Maintenance	PVTM(LOW)	PVTM(SHARED)
Present Value Total Cost	PVCOST(LOW)	PVSHR

PRINT:

FOR MULTI-USER

Capital Costs	
On-Vehicle Equipment	GTLS(I)
Signposts	GTSP(I)
Remote Receivers	GTRR(I)
Communications	
Basic	GTBCOM(I)
Variable	GTECOM(I)
Data Processing	
Basic	GTBDP(I)
Variable	GTEDP(I)
Grand Total	TOT(I)
Annual Maintenance Costs	
On-Vehicle Equipment	GTLSM(I)
Signposts	GTSPM(I)
Remote Receivers	GTRRM(I)
Communications	
Basic	GTBCMM(I)
Variable	GTEDPM(I)
Total Annual Maintenance	TOTM(I)
Present Value	PVTM(I)
Present Value of Total Cost	PVCOST(I)

AVM COST PROGRAM



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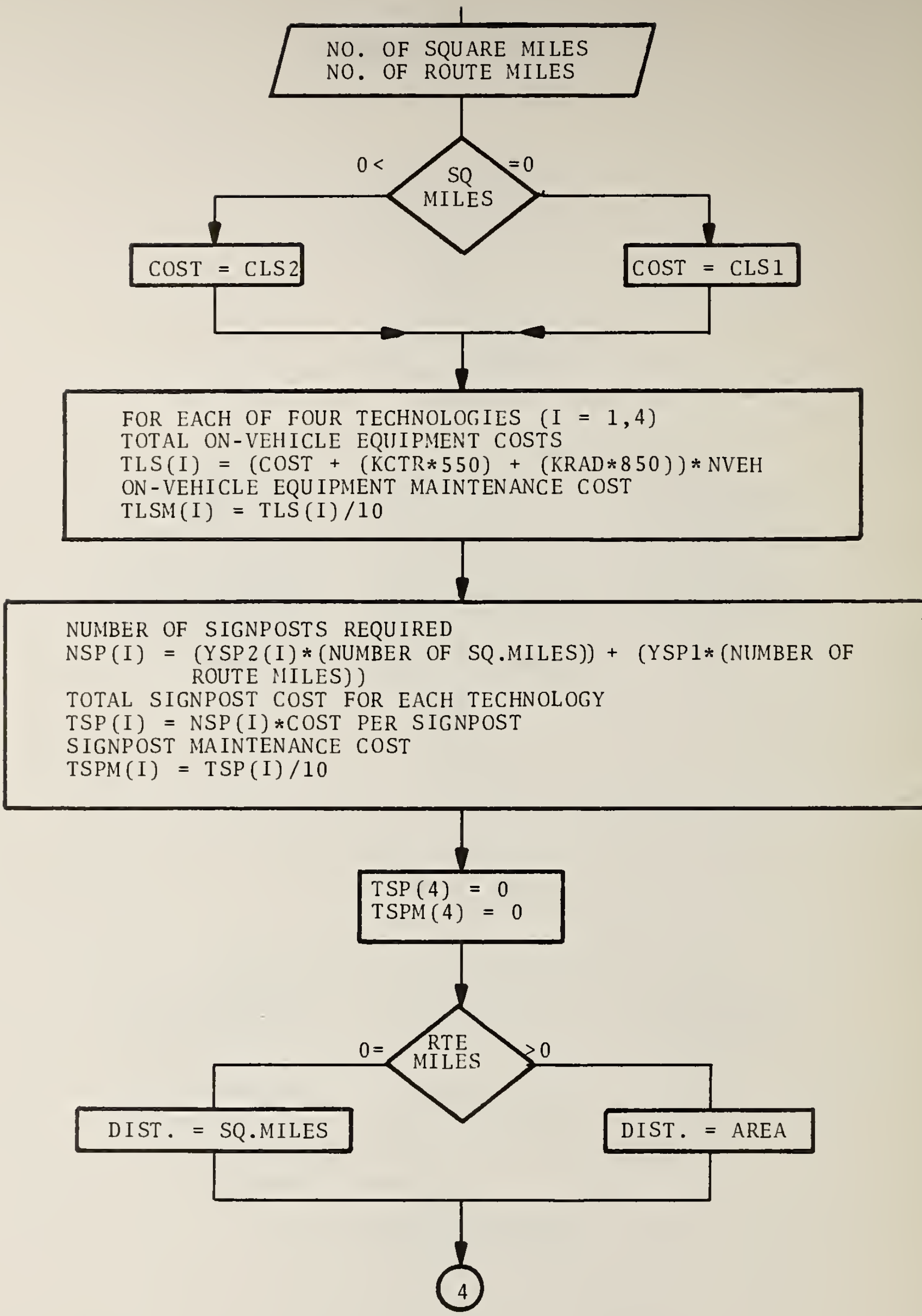

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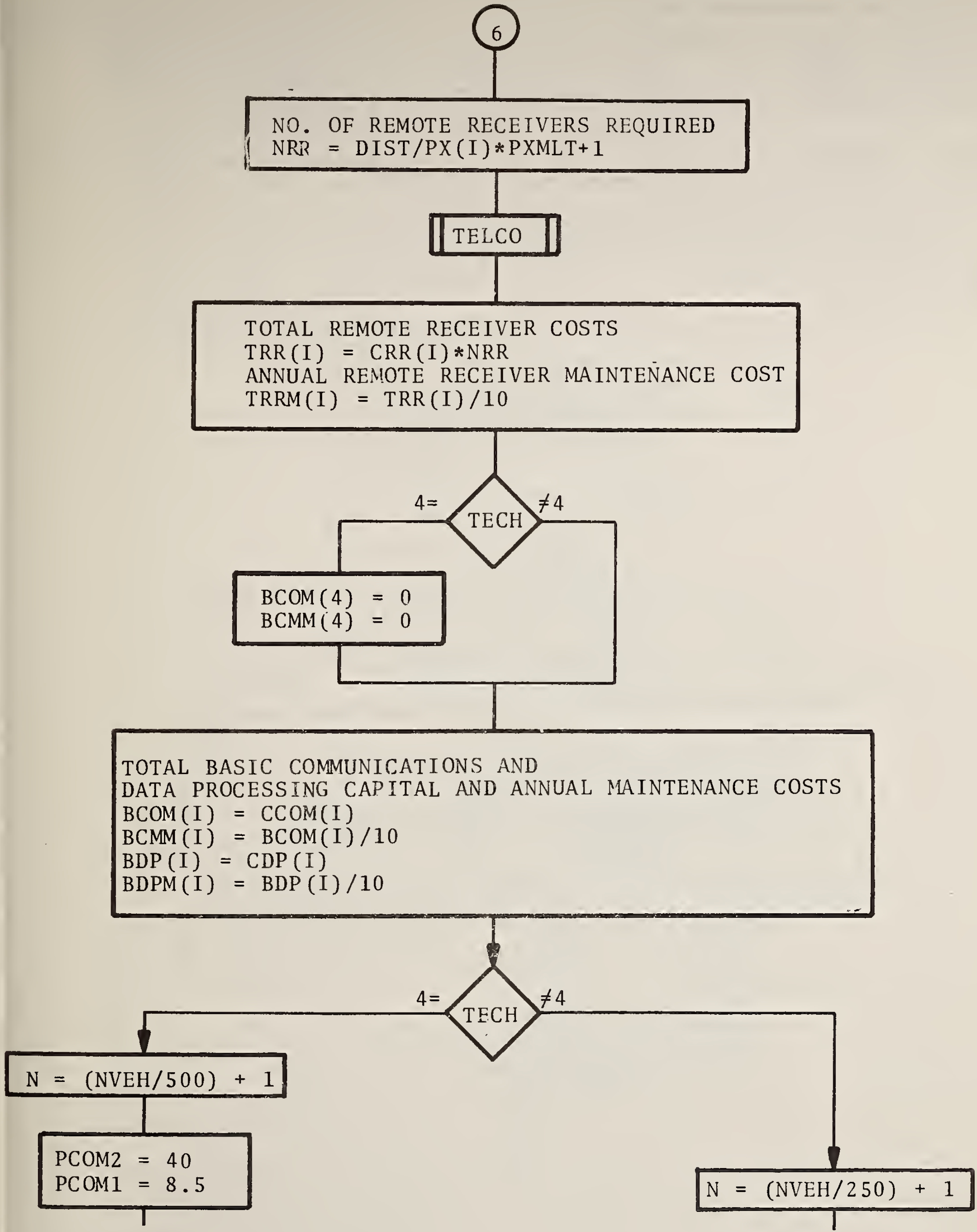

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INCREMENTAL COMMUNICATIONS CAPITAL AND ANNUAL MAINTENANCE COST FOR DEAD-RECKONING AVM

ECOM(4) = PCOM*N

ECMM(4) = ECOM(4)/10

N = (NVEH/250) + 1

INCREMENTAL COMMUNICATIONS CAPITAL AND ANNUAL MAINTENANCE COSTS

ECOM(I) = N

ECMM(I) = ECOM(I)/10

TOTAL INCREMENTAL DATA PROCESSING CAPITAL AND ANNUAL MAINTENANCE COSTS.

EDP(I) = CEDP(I)*N

EDPM(I) = EDP(I)/10

TOTAL CAPITAL COSTS:

TOT(I) = TLS(I) + TSP(I) + TRR(I) + BCOM(I) + ECOM(I) + BDP(I) + EDP(I)

TOTAL ANNUAL MAINTENANCE COST

TOTM(I) = TLSM(I) + TSPM(I) + TRRM(I) + BCMM(I) + ECMM(I) + BDPM(I) + EDPM(I)

PRESENT VALUE TOTAL MAINTENANCE

PVTM(I) = PV(TOTM(I))

PRESENT VALUE OF TOTAL COST

PVCOST(I) = PVTM(I) + TOT(I)

PRINT

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MAINTAIN RUNNING TOTAL OF UNIQUE EQUIPMENT FOR FINAL WRAP-UP (GTLS, GTLSM, GTECOM, GTECMM, GTEDP, GTEDPM)

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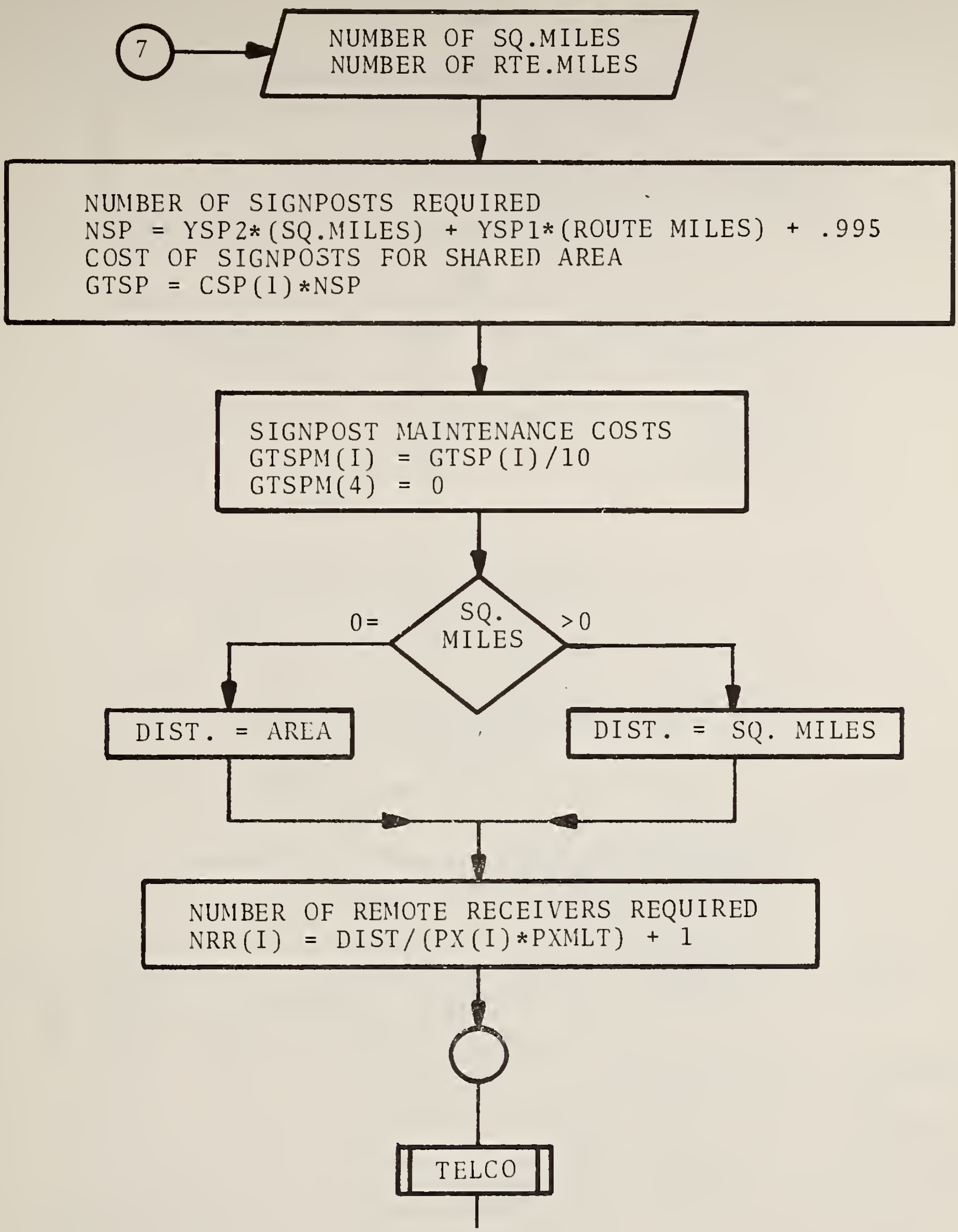

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```
COST OF REMOTE RECEIVERS FOR SHARED AREA
GTRR(I) = CRR(I)*NRR
REMOTE RECEIVER MAINTENANCE COST
GTRRM(I) = (GTRR(I)/10) + √DIST*F*120
```

```
BASIC COMMUNICATIONS CAPITAL AND ANNUAL
MAINTENANCE COSTS
GTBCOM(I) =  BCOM(I)
GTBCMM(I) = GTBCOM(I)/10
GTBCOM(4) = 0
GTBCMM(4) = 0
```

```
TOTAL SHARED DATA PROCESSING
CAPITAL AND ANNUAL MAINTENANCE COSTS
GTBDP(I) = CDP(I)
GTBDPM(I) = GTBDP(I)/10
```

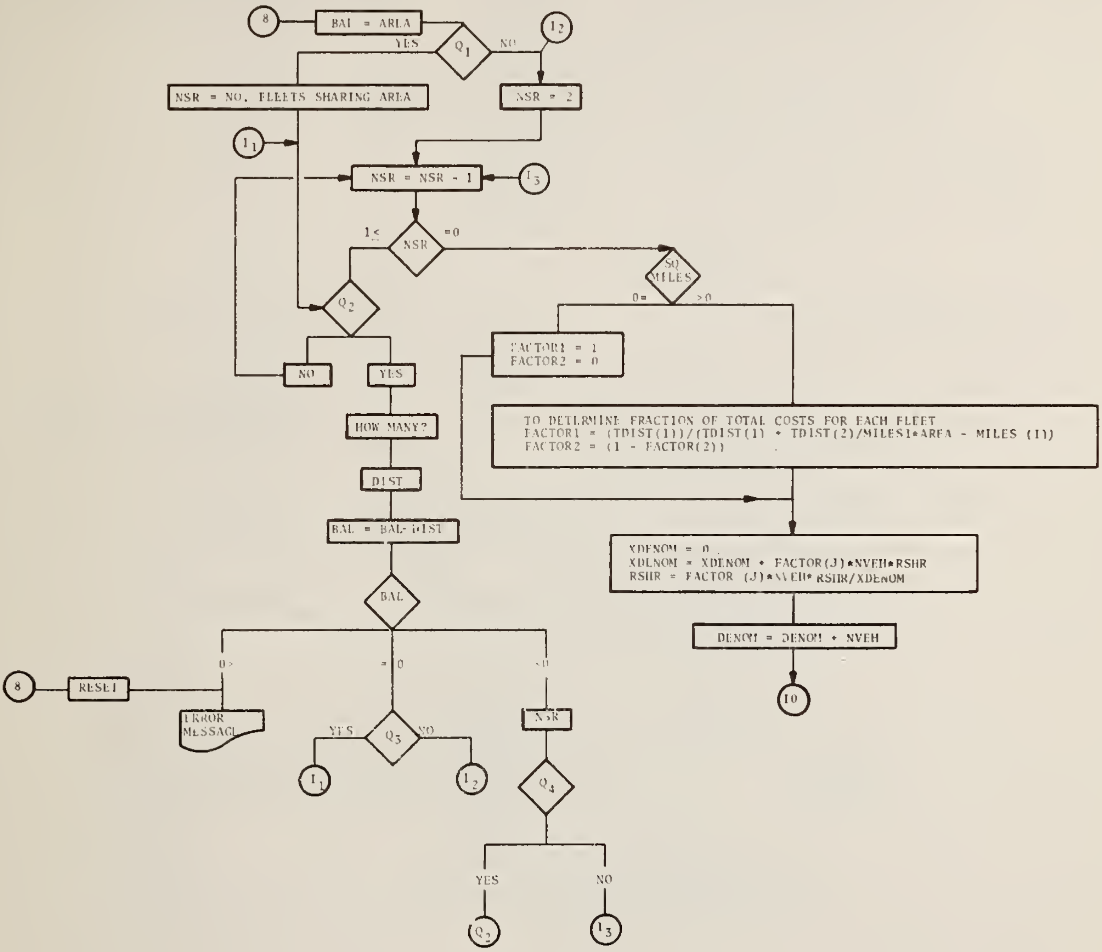
```
TOTAL CAPITAL COSTS
TOT(I) = GTLS(I) + GTSP(I) + GTRR(I) + GTBCOM(I)
       + GTBDP(I) + GTECOM(I) + GTEDP(I)

TOTAL MAINTENANCE COSTS
TOTM(I) = GTLSM(I) + GTSPM(I) + GTRRM(I) + GTBCMM(I)
        + GTBDPM(I) + GTECMM(I) + GTEDPM(I)

PRESENT VALUE TOTAL MAINTENANCE
PVTM(I) = PV(TOTM(I))

PRESENT VALUE TOTAL COST
PRCOST(I) = PVTM(I) + TOT(I)
```

PRINT

8

(CONTINUED NEXT PAGE)

Q_1 - DO DIFFERENT FLEETS SERVE OVERLAPPING AREAS?
Q_2 - ANY AREA SERVED BY NSR USERS?
Q_3 - DO DIFFERENT FLEETS SERVE OVERLAPPING ROUTE MILES?
Q_4 - ANY OTHER SECTOR SERVED BY NSR USERS?



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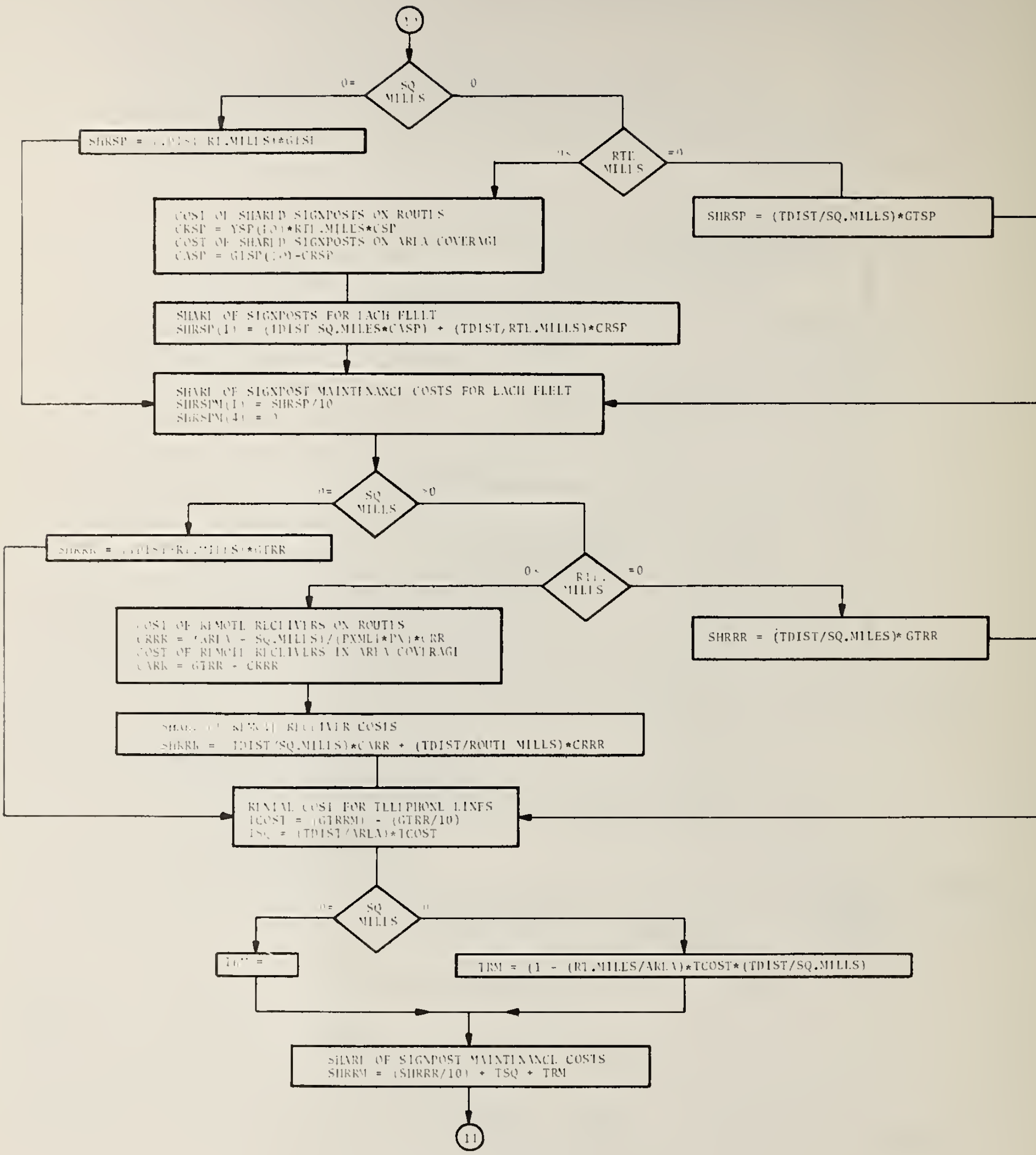

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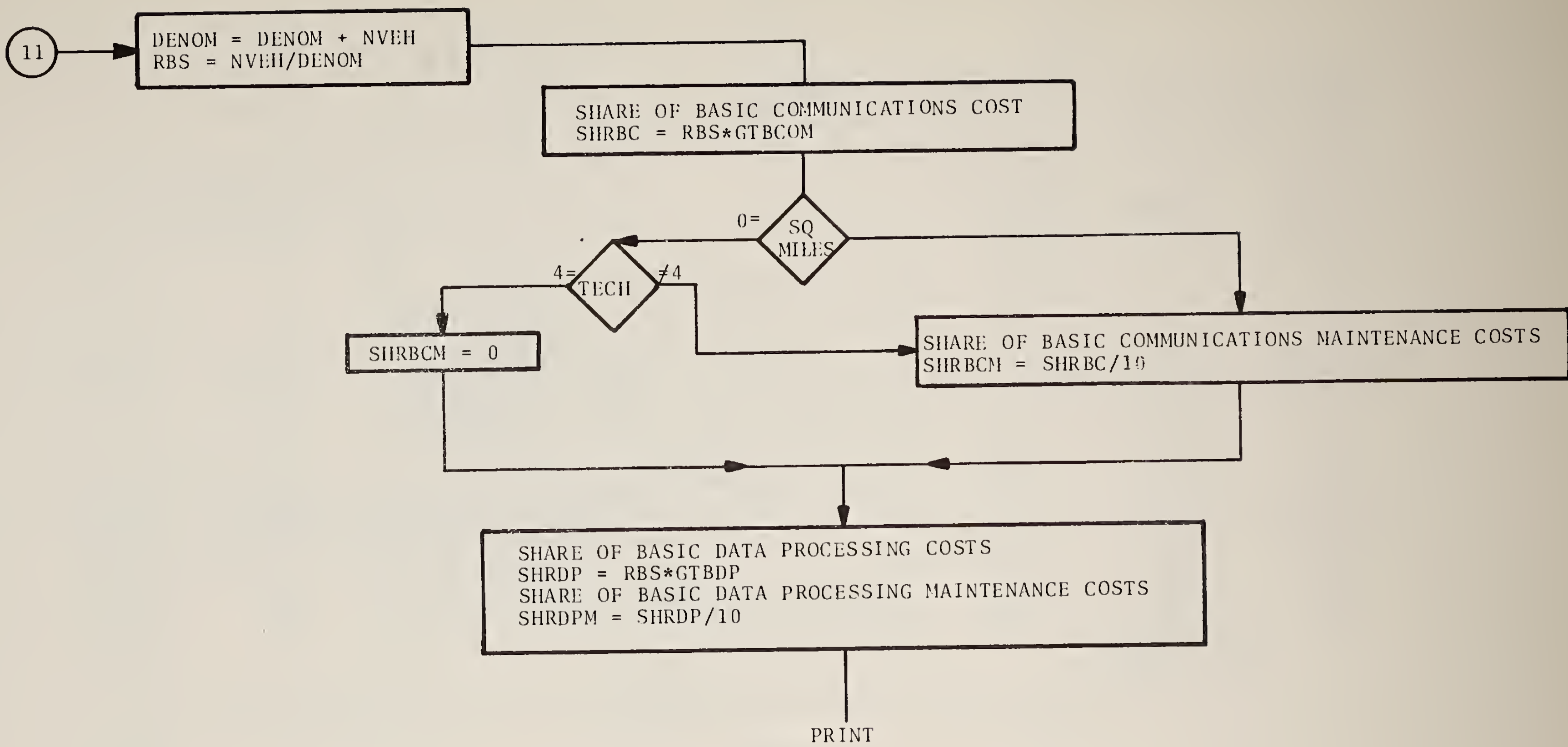
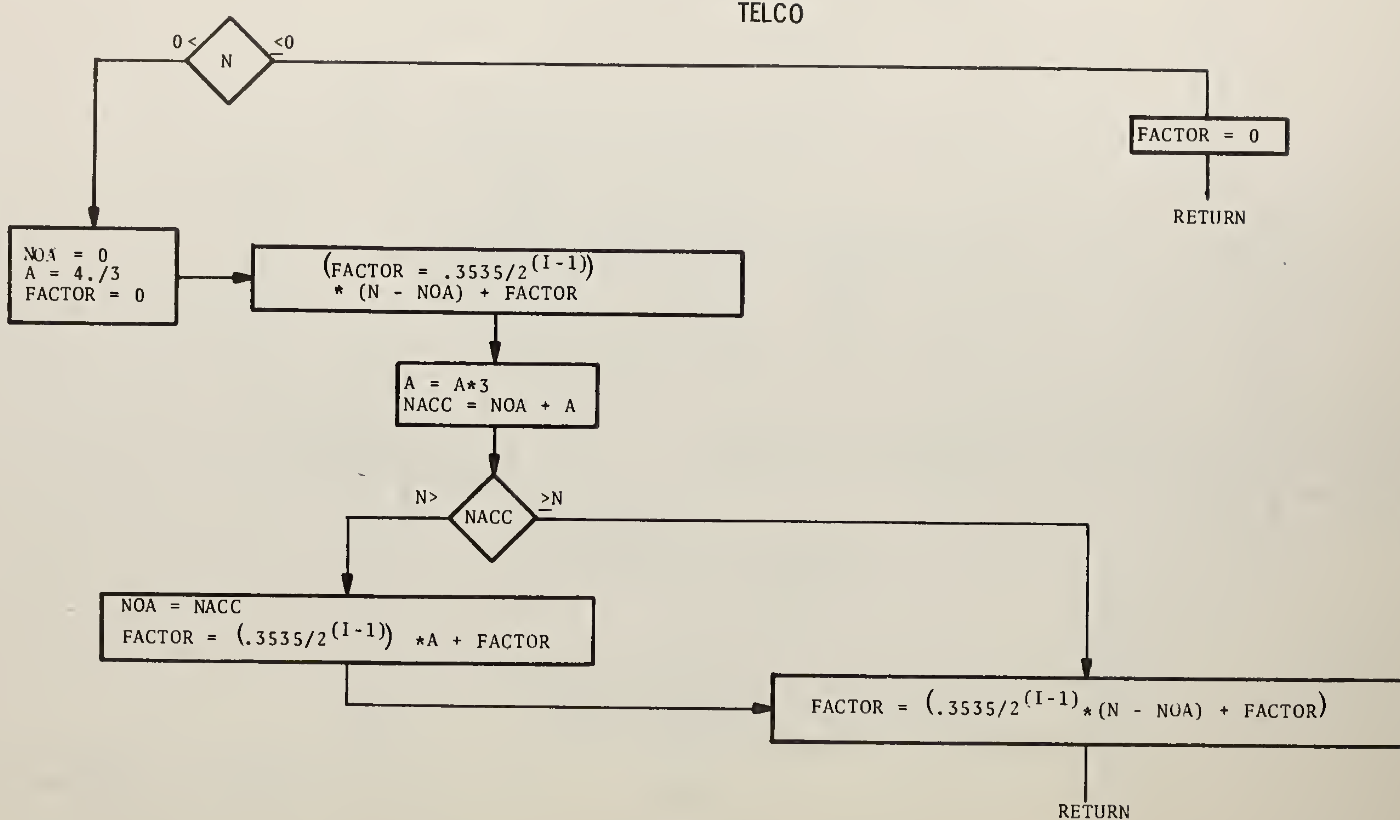


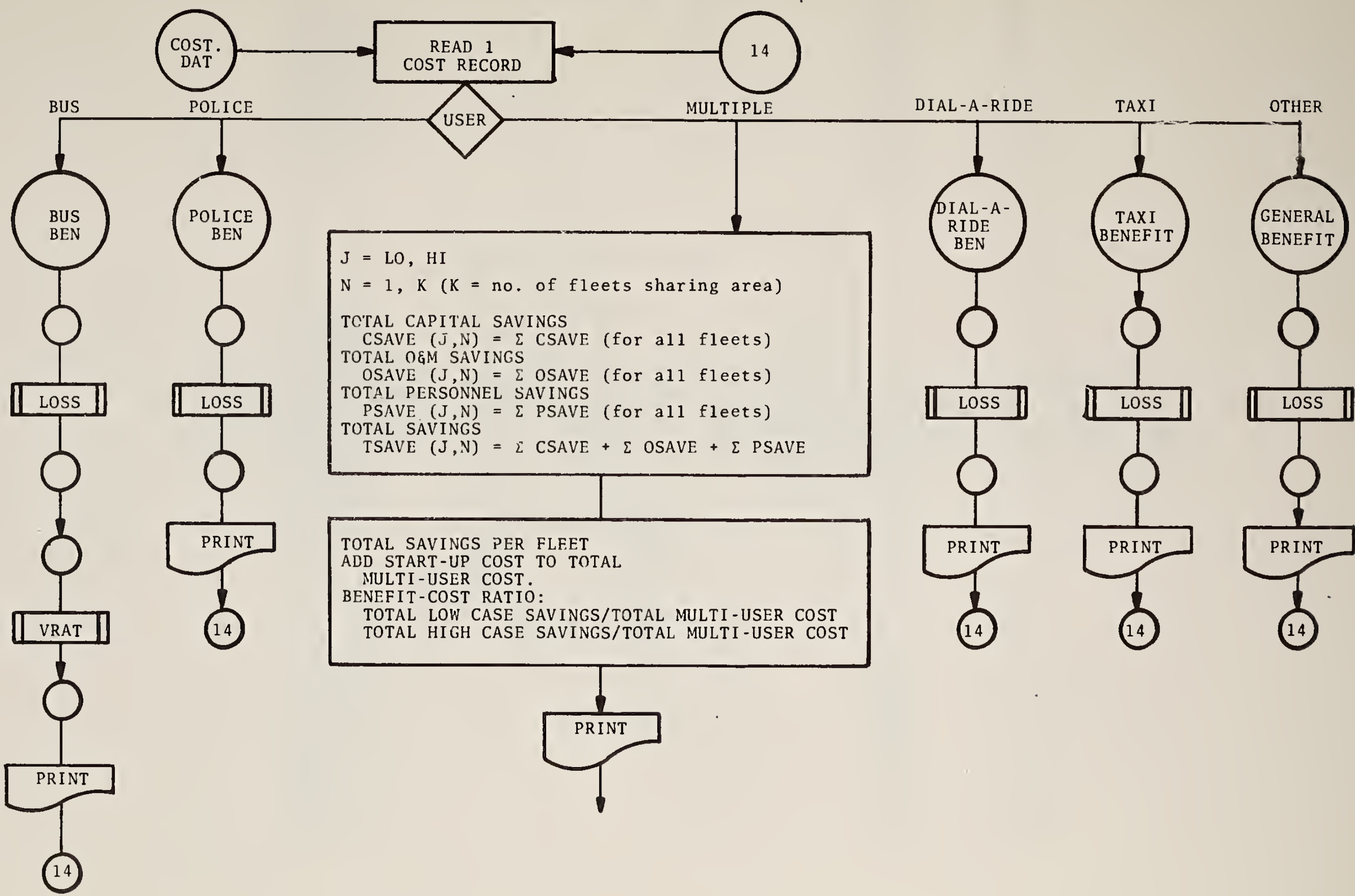
(END FLOW DIAGRAM)

TELCO

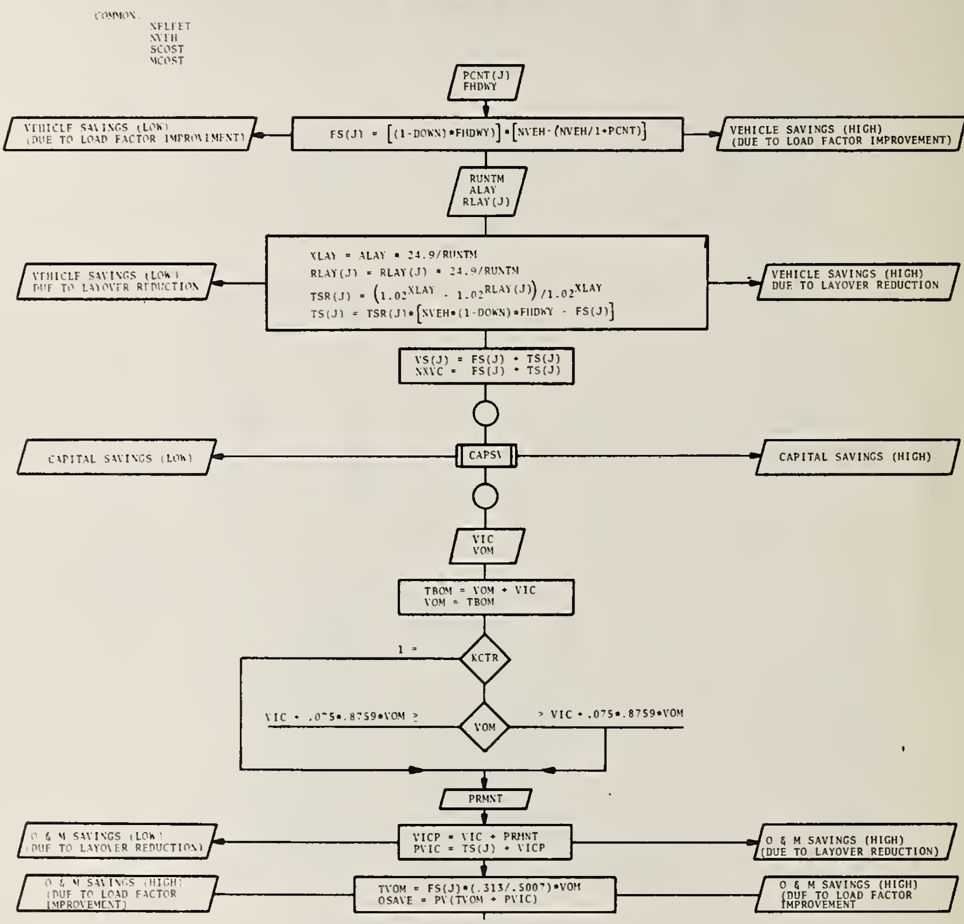


N
0 <
<0
FACTOR = 0
RETURN
NOA = 0
A = 4./3
FACTOR = 0
(FACTOR = .3535/2^(I-1))
* (N - NOA) + FACTOR
A = A*3
NACC = NOA + A
NACC
N>
>N
NOA = NACC
FACTOR = (.3535/2^(I-1)) *A + FACTOR
FACTOR = (.3535/2^(I-1) * (N - NOA) + FACTOR)
RETURN

AVM BENEFIT PROGRAM



BUS BENEFIT ALGORITHM



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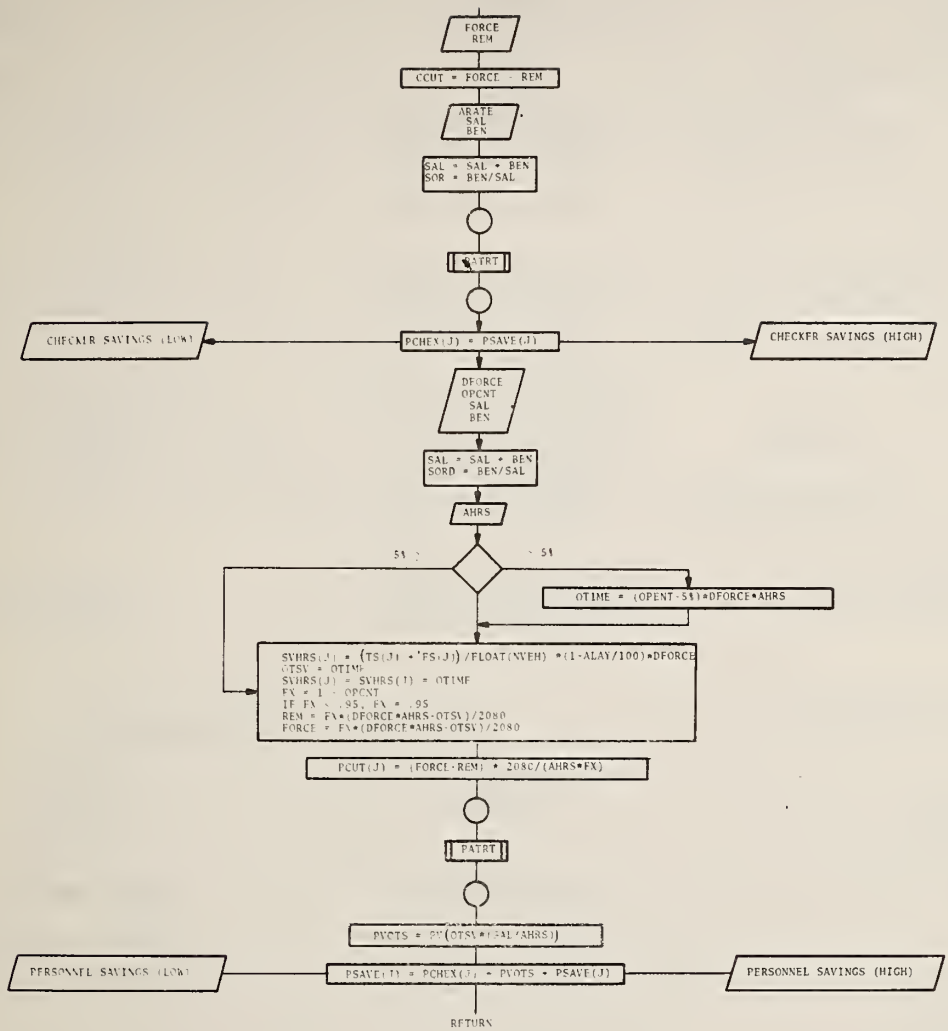


(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: BUS

Savings Source	Layover Reduction Low	Layover Reduction High
% Change	PLAY(LO)	PLAY(HI)
Vehicles Saved	TS(LO)	TS(HI)
Capital	VDAT(1)*CSAVE(LO)	VDAT(2)*CSAVE(HI)
O&M	VDAT(1)*OSAVE(LO)	VDAT(2)*OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	VDAT(1)*PCUT	VDAT(2)*PCUT
Salary	((1-SORD)*(PSAVE(LO) -PCHEX(LO))*VDAT(1)	((1-SORD)*(PSAVE(HI) -PCHEX(HI))*VDAT(2)
Overhead & Ben	((SORD)*(PSAVE(LO) -PCHEX(LO))*VDAT(1)	((SORD)*(PSAVE(HI) -PCHEX(HI))*VDAT(2)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST

Savings Source	Load Factor Improvement Low	Load Factor Improvement High
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	FS(LO)	FS(HI)
Capital	VDAT(3)*CSAVE(LO)	VDAT(4)*CSAVE(HI)
O&M	VDAT(3)*OSAVE(LO)	VDAT(4)*OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	VDAT(3)*PCUT	VDAT(4)*PCUT
Salary	((1-SOR)*(PSAVE(LO) -PCHEX(LO))*VDAT(3)	((1-SOR)*(PSAVE(HI) -PCHEX(HI))*VDAT(4)
Overhead & Ben	((SOR)*(PSAVE(LO) -PCHEX(LO))*VDAT(3)	((SOR)*(PSAVE(LO) -PCHEX(HI))*VDAT(4)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST

Data Collection

	Low	High
Personnel Saved	CCUT	CCUT
Salary	(1-SOR)*PCHEX(LO)	(1-SOR)*PCHEX(HI)
Overhead & Ben	SOR*PCHEX(LO)	SOR*PCHEX(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Total Savings	Total Above(LO)	Total Above(HI)
Total Costs		
Single User	SCOST	SCOST
Multiple User	MCOST	MCOST
Benefit-Cost Ratios	Total(LO)/SCOST Total(LO)/MCOST	Total(HI)/SCOST Total(HI)/MCOST

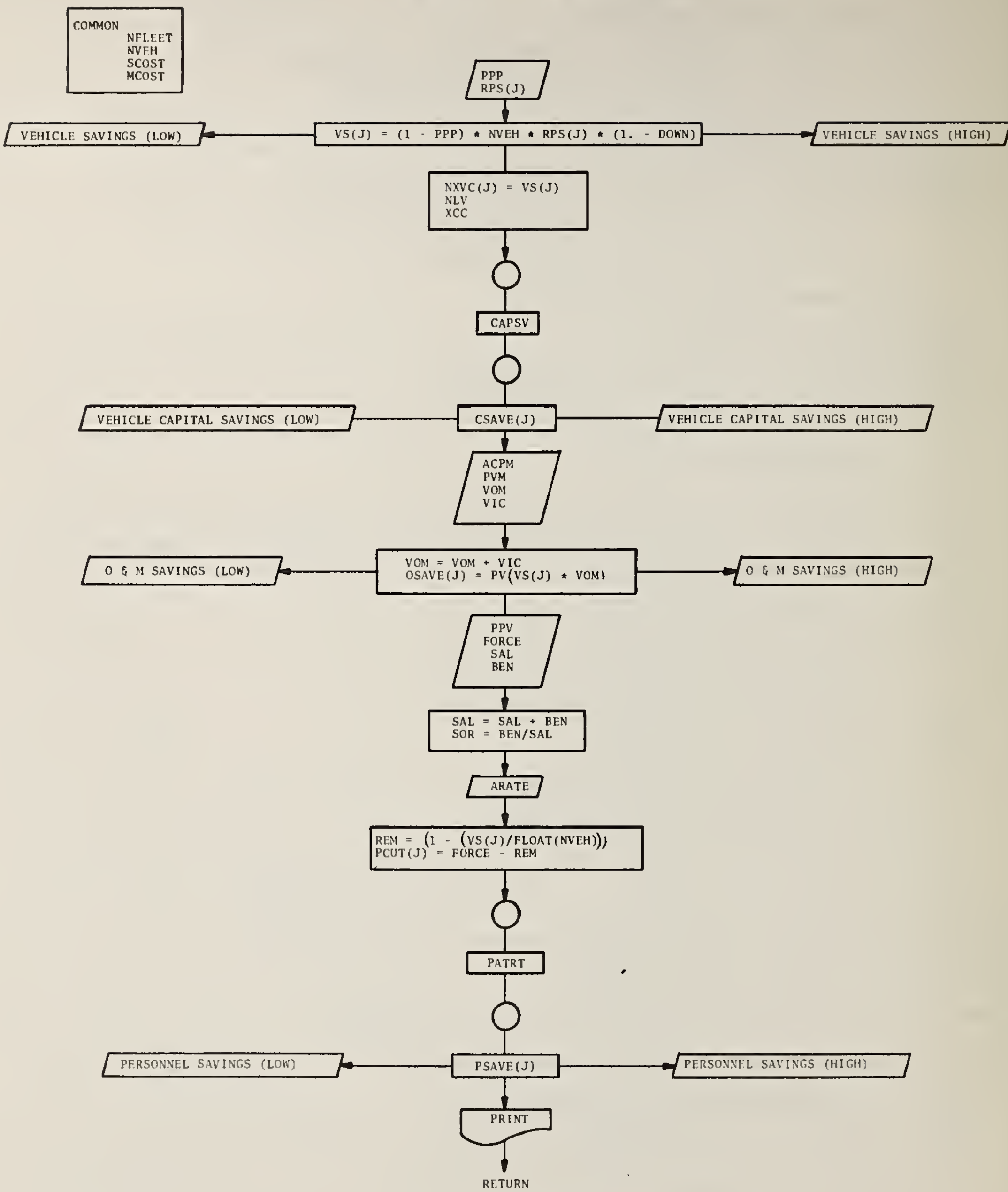
Detail Data for Bus

L.F. Improvement (%)	PCNT(LO)	PCNT(HI)
%Buses on Freq. Headway	FHDWY	
L.F. Savings (VEH)	FS(LO)	FS(HI)
1-Way Avg. Run Time	RUNTM	
Layover Time, Pres. & Goals	ALAY RLAY(LO)	RLAY(HI)
Layover Time Veh Savings	TS(LO)	TS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
Insurance	VIC	
Periodics	PRMNT	
O&M Savings: Layover, L.F.	PVIC(LO)	TVOM(LO)
O&M Savings: Layover, L.F.	PVIC(HI)	TVOM(HI)
O&M Savings	OSAVE(LO)	OSAVE(HI)
Checker Force	FORCE	
Retained	REM	
Attrition Rate	ARATE	
Cost per Checker	SAL+BEN	
Checker Savings	PCHEX	
Driver Force	DFORCE	
Overtime(%)	OTIME	
Cost per Driver	SAL+BEN	
Attrition Rate	ARATE	
Current Value of Hours Saved	SVHRS(LO)	
Equiv. Driver Force	FORCE	
Drivers Remaining	REM	
Savings of Drivers Salaries	OTSV(LO)	
PV of Overtime Cut	PVOTS(LO)	
Current Value of Hours Saved	SVHRS(HI)	
Equiv. Driver Force	FORCE	
Drivers Remaining	REM	
Savings of Drivers Salaries	OTSV(HI)	
PV of Overtime Cut	PVOTS(HI)	
Personnel Savings	PSAVE(LO)	PSAVE(HI)

Key for Bus Benefit Algorithm

(J):	Low, High Parameters
FS:	Vehicles Saved Due to Load Factor Improvement
TS:	Vehicles Saved Due to Layover Reduction
VS:	Total Vehicles Saved
DOWN:	Fraction of Fleet in Maintenance (Average)
FHDWY:	Fraction of Fleet on Frequent Headway Routes During Peak
VIC:	Annual Insurance Cost per Vehicle
VOM:	Annual O&M Cost per Vehicle
OSAVE:	Total O&M Savings
PCNT:	Expected Load Factor Improvement
RUNTM:	Average One-Way Runtime
ALAY:	Average Layover Time
RLAY:	Layover Goal
PRMNT:	Fraction of O&M Done According to the Calendar for Each Vehicle
CSAVE:	Total Capital Savings
FORCE:	Initial Checker Force
REM:	Necessary Checker Force Required
CCUT:	Total Checker Reduction
ARATE:	Checker Attrition Rate
SAL:	Average Salary per Checker
BEN:	Average Benefits per Checker
SOR:	Ratio of Benefits to Total Salary for Checkers
PSAVE:	Personnel Savings
VDAT(1):	Ratio of Vehicles Saved Due to Layover Reduction
VDAT(2):	to Total Vehicles Saved
VDAT(3):	Ratio of Vehicles Saved Due to Load Factor
VDAT(4):	Improvement to Total Vehicles Saved
SCOST:	Single-User AVM Deployment Cost
MCOST:	Multiple-User AVM Deployment Cost

POLICE BENEFIT ALGORITHM



(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR POLICE

Savings Source	Response Time Reduction	
	Low	High
% Change	RPS(LO)	RPS(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital	CSAVE(LO)	CSAVE(HI)
O&M	OSAVE(LO)	OSAVE(HI)
Subtotal	CSAVE(LO)+OSAVE(LO)	CSAVE(HI)+OSAVE(HI)
Item B/C		
Single User	SUBTOTAL/SCOST	SUBTOTAL/SCOST
Multiple User	SUBTOTAL/MCOST	SUBTOTAL/MCOST
Patrolman Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*RSAVE(LO)	(1-SOR)*PSAVE(HI)
Overhead+Benefits	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	TOTAL ABOVE	TOTAL ABOVE
System Costs		
Single User	SCOST	SCOST
Multiple User	MCOST	MCOST
Benefit-Cost Ratios		
Single User	TOTAL(LO)/SCOST	TOTAL(HI)/SCOST
Multiple User	TOTAL(LO)/MCOST	TOTAL(HI)/MCOST

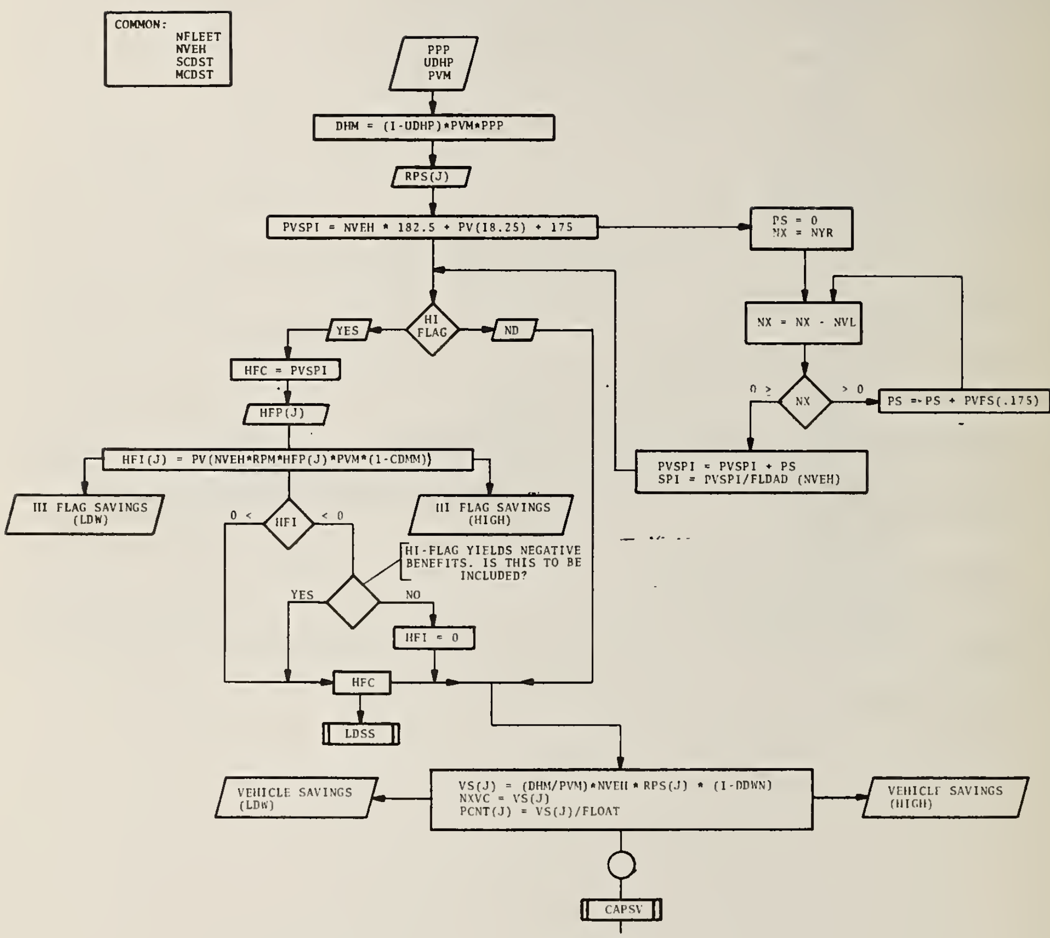
Detail Data for Police

% of Miles for Preventive Patrol	PPP	
Low, High % Savings on Response Miles	RPS(LO)	RPS(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
Cost per Mile	ACPM	
Vehicle Miles per Year	PVM	
Insurance Costs per Vehicle	VIC	
Total O&M & Insurance	VOM+VIC	
O&M Savings (PV)	OSAVE(LO)	OSAVE(HI)
Direct Personnel per Vehicle	PPV	
Annual Salary	SAL	
Annual Cost per Person	SAL+BEN	
Attrition Rate	ARATE	
Initial Force	FORCE	
Balance Remaining	REM(LO)	
Personnel Cut	PCUT(LO)	
Balance Remaining	REM(HI)	
Personnel Cut	PCUT(HI)	
Personnel Savings (PV)	PSAVE(LO)	PSAVE(HI)

Key to Police Benefit Algorithm

J:	Low, High Parameters
PPP:	% of Total Mileage Spent in Preventive Patrol
RPS:	% of Mileage Spent in Response to Calls Expected to be Saved
DOWN:	% of Vehicles in Maintenance (Average)
VS:	Vehicles Saved
XCC:	Cost of New Vehicle, Less Salvage Value
NVL:	Expected Vehicle Life
ACPM:	O&M Cost per Mile
PVM:	Annual Miles per Car
VIC:	Annual Insurance Cost per Car
VOM:	Annual O&M Cost per Vehicle
PPV:	Persons per Vehicle
FORCE:	Initial Patrolman Force
SAL:	Average Annual Patrolman's Salary
BEN:	Average Annual Benefits for Patrolman
SOR:	Ratio of Overhead to Total Personnel Costs for Patrolmen
ARATE:	Attrition Rate
REM:	Remaining Patrol Force
PCUT:	Total Force Reduction
CSAVE:	Capital Savings
OSAVE:	O&M Savings
PSAVE:	Personnel Savings

TAXI BENEFIT ALGORITHM



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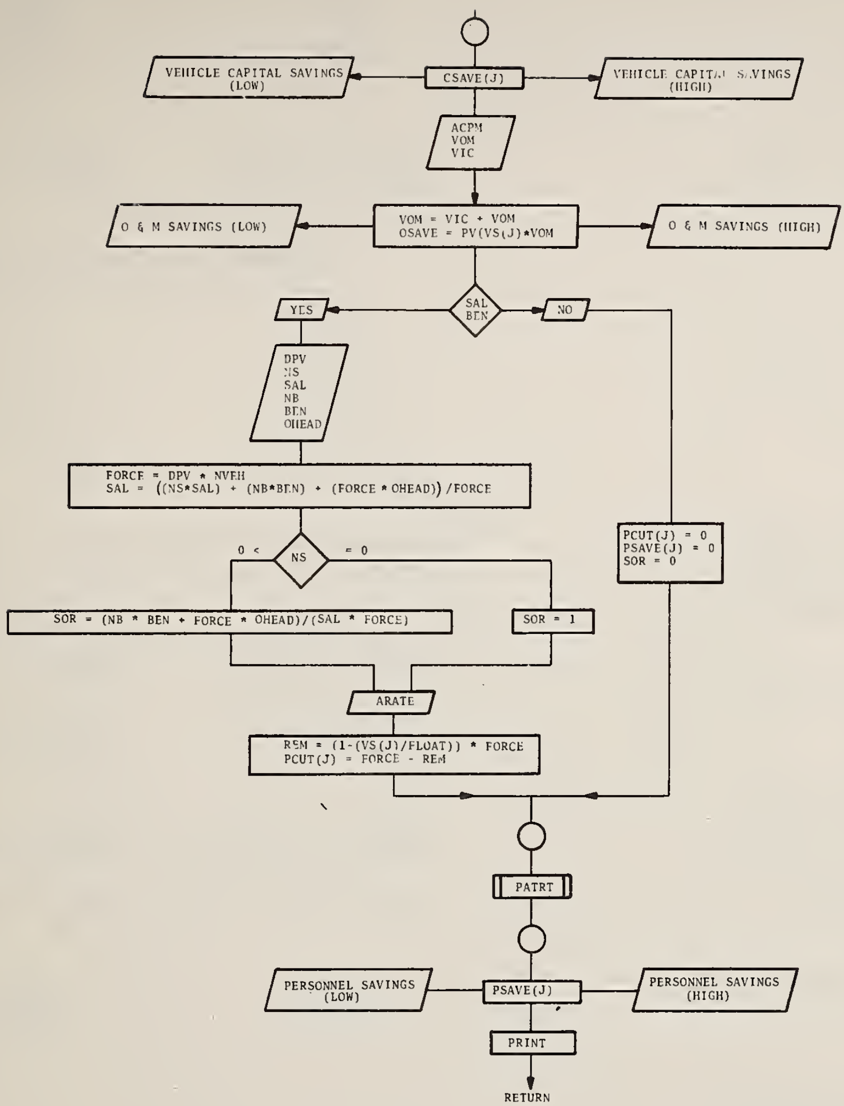
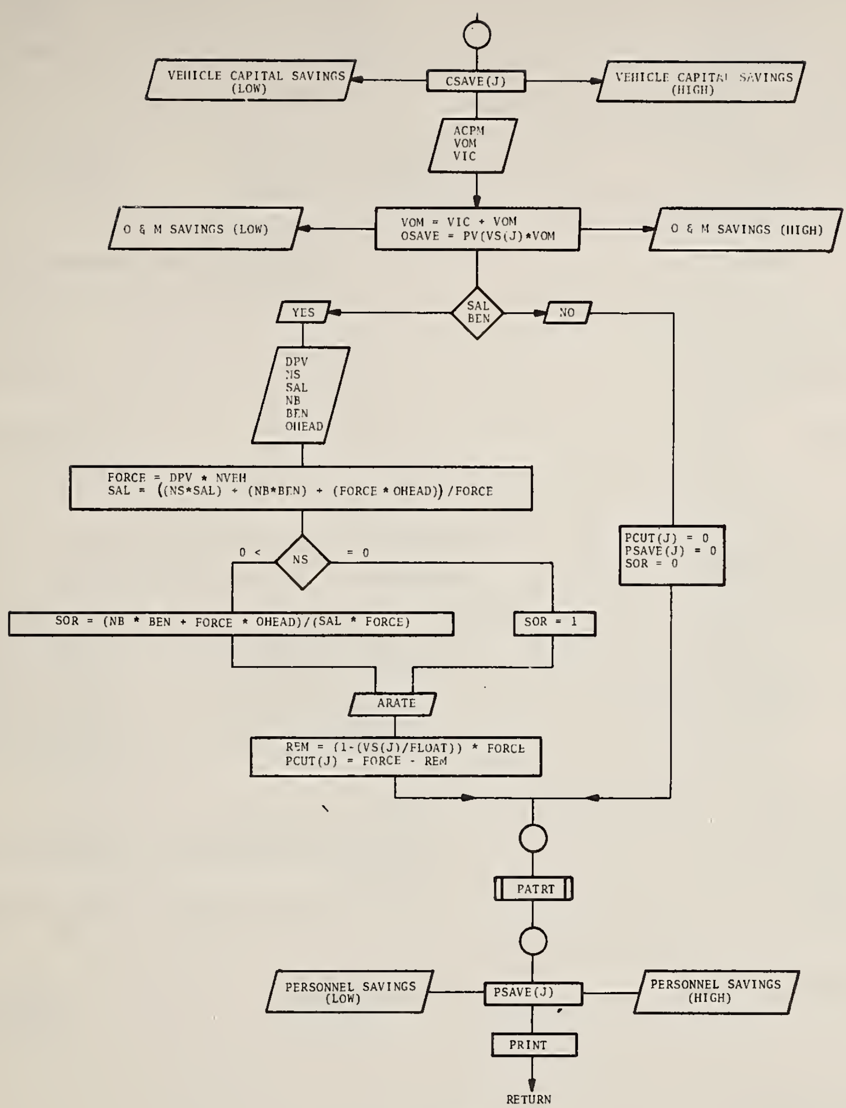


(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: TAXI

Source of Savings	"High-Flagging" Reduction	
	Low	High
% Change	HFP(LO)	HFP(HI)
Revenue Increase	HFI(LO)	HFS(HI)
Item B/C		
Single User	HFI(LO)/SCOST	HFI(HI)/SCOST
Multiple User	HFI(LO)/MCOST	HFI(HI)/MCOST
	Reduce Dead-Head Miles	
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
O&M Savings	OSAVE(LO)	OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Overhead & Ben	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	Total Above(LO)	Total Above(HI)
System Costs	SCOST MCOST	SCOST MCOST
Benefit-Cost Ratio		
Single User	Total(LO)/SCOST	Total(HI)/SCOST
Multiple User	Total(LO)/MCOST	Total(HI)/MCOST



(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: TAXI

Source of Savings	"High-Flagging" Reduction	
	Low	High
% Change	HFP(LO)	HFP(HI)
Revenue Increase	HFI(LO)	HFS(HI)
Item B/C		
Single User	HFI(LO)/SCOST	HFI(HI)/SCOST
Multiple User	HFI(LO)/MCOST	HFI(HI)/MCOST
	Reduce Dead-Head Miles	
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
O&M Savings	OSAVE(LO)	OSAVE(HI)
Subtotal	Subtotal Above	Subtotal Above
Item B/C		
Single User	Subtotal(LO)/SCOST	Subtotal(HI)/SCOST
Multiple User	Subtotal(LO)/MCOST	Subtotal(HI)/MCOST
Drivers Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Overhead & Ben	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	Total Above(LO)	Total Above(HI)
System Costs	SCOST MCOST	SCOST MCOST
Benefit-Cost Ratio		
Single User	Total(LO)/SCOST	Total(HI)/SCOST
Multiple User	Total(LO)/MCOST	Total(HI)/MCOST

Detail Data for Taxi

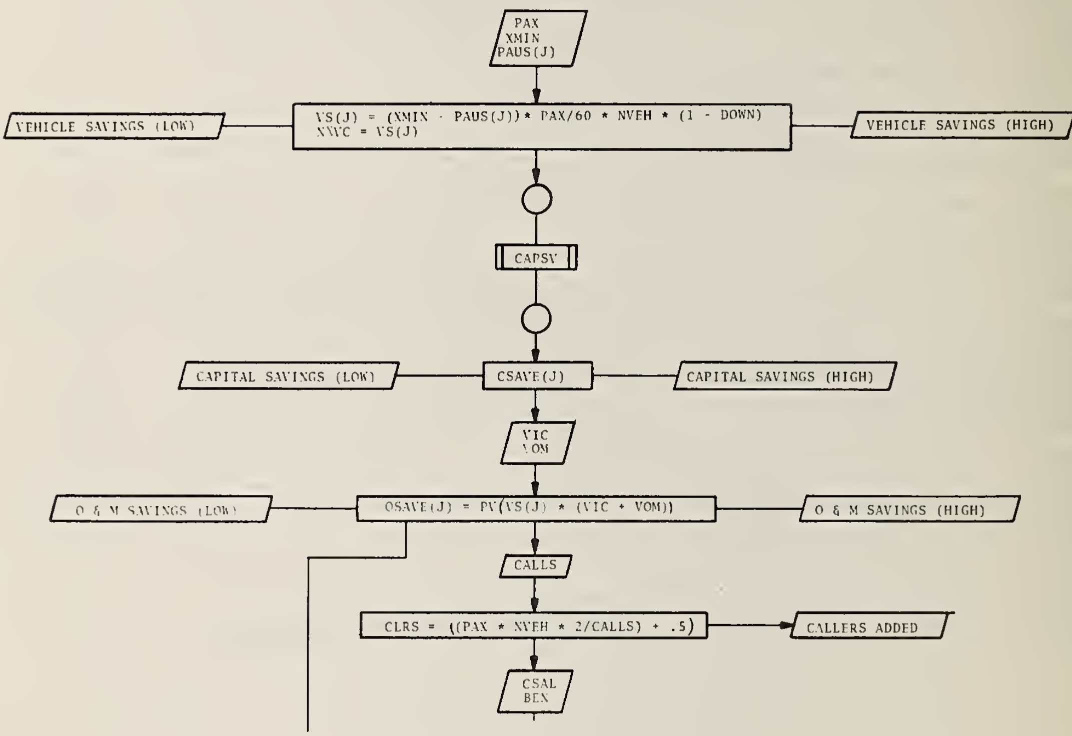
Dead-Head Miles (%)	PPP	
Unavoidable Dead-Head (%)	UDHP	
Average Annual Miles-	PVM	
Dead-Head Miles per Vehicle	DHM	
Low, High Mileage Savings	RPS(LO), RPS(HI)	
Vehicles Saved	VS(LO)	
Capital Savings, Vehicles (PV)	CSAVE(LO)	
Vehicles Saved	VS(HI)	
Capital Savings, Vehicles (PV)	CSAVE(HI)	
O&M Cost per Mile	ACPM	
O&M Costs per Vehicle	VOM	
Insurance Costs	VIC	
O&M Savings (PV)	OSAVE(LO)	OSAVE(HI)
Drivers	FORCE	
Cost per Driver	SAL	
Attrition Rate	ARATE	
Personnel Cut	PCUT(LO)	
Personnel Cut	PCUT(HI)	
Personnel Savings (PV)	PSAVE(LO)	PSAVE(HI)

Key to Taxi Benefit Algorithm

(J):	High, Low Parameters
PPP:	% of Total Vehicle Mileage that is Non-Revenue Deadhead
UDHP:	% if Total Mileage that is Unavoidable Non-Revenue
PVM:	Annual Vehicle Mileage
DHM:	Avoidable Dead-Head Miles
RPS:	% of Avoidable Dead-Head Miles
PVSPI:	Present Value Cost of High-Flag Equipment
SPI:	Cost of High-Flag Equipment per Vehicle
NX:	Year Counter
NYR:	System Life
NVL:	Vehicle Life
HFC:	Total High-Flag Equipment Costs
HFP:	% Increase in Revenue Expected from "High-Flag" Reduction
HFI:	Increase in Revenue Expected from "High-Flag" Reduction
VS:	Vehicle Savings
DOWN:	% of Fleet in Maintenance(Average)

PCNT: % Reduction in Fleet
CSAVE: Capital Savings
HCPM: O&M Costs per Mile
VOM: Annual O&M Costs per Vehicle
VIC: Annual Insurance Costs per Vehicle
OSAVE: O&M Savings
DPV: Drivers per Vehicle
NS: Number of Drivers on Salary
SAL: Average Annual Salary per Driver
NB: Number of Drivers Receiving Benefits
BEN: Average Dollar Value of Annual Benefits
OHEAD: Average Dollar Value of Annual Overhead for Entire Fleet
FORCE: Total Driver Force
SOR: Ratio of Benefits to Total Salary and Benefits
ARATE: Attrition Rate
REM: Minimum Work Force Required
PCUT: Personnel Attrited
PSAVE: Personnel Savings
SCOST: Single User AVM Deployment Cost
MCOST: Share of Costs of a Multiple User AVM System

DIAL-A-RIDE BENEFIT ALGORITHM



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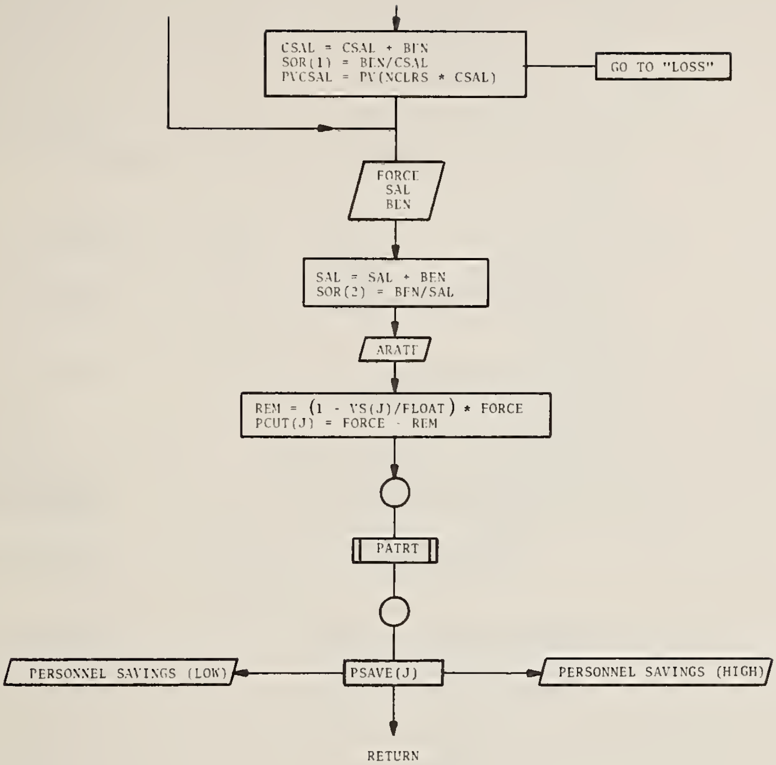


(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR DIAL-A-RIDE

Savings Source	Response Time Reduction	
	Low	High
% Change	PCNT(LO)	PCNT(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital	CSAVE(LO)	CSAVE(HI)
O&M	OSAVE(LO)	OSAVE(HI)
Subtotal	CSAVE(LO)+OSAVE(LO)	CSAVE(HI)+OSAVE(HI)
Item B/C		
Single User	SUBTOTAL/SCOST	SUBTOTAL/SCOST
Multiple User	SUBTOTAL/MCOST	SUBTOTAL/MCOST
Personnel Cut	PCUT(LO)	PCUT(HI)
Personnel Savings		
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Benefits	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(HI)/MCOST	PSAVE(HI)/MCOST
Callers Added	CLRS	CLRS
Cost of Callers	CCOST	CCOST
Total Savings	TOTAL ABOVE	TOTAL ABOVE
Total Costs	SCOST	SCOST
	MCOST	MCOST
Benefit-Cost Ratios		
Single User	TOTAL(LO)/SCOST	TOTAL(HI)/SCOST
Multiple User	TOTAL(LO)/MCOST	TOTAL(HI)/MCOST

Detail Data for Dial-a-Ride

Passengers per Hour	PAX	
Dwell Time for Stop (min)	XMIN	
Low, High Dwell Time Goal	PAUS(LO)	PAUS(HI)
Vehicles Saved	VS(LO)	
Vehicles Saved	VS(HI)	
Capital Savings	CSAVE(LO)	CSAVE(HI)
Insurance/Vehicle	VIC	
Periodic Maintenance	VOM	
O&M Savings	OSAVE(LO)	OSAVE(HI)
Calls per Caller per Hour	CALLS	
Callers	CLRS	
Cost per Caller per Year	CSAL+BEN	
Drivers	FORCE	
Cost per Driver per Year	SAL+BEN	
Attrition Rate	ARATE	
Drivers Cut	PCUT(LO)	
Drivers Cut	PCUT(HI)	
Driver Savings	PSAVE(LO)	PSAVE(HI)

Key to Dail-A- Ride Benefit Algorithm

J: Low, High Parameters

PAX: Passengers Served Per Hour

XMIN: Average Dwell Time Per Stop

PAUS: Dwell Time Goals

VS: Vehicles Saved

CSAVE: Capital Savings

VIC: Annual Insurance Cost Per Vehicle

VOM: Annual O&M Cost per Vehicle

OSAVE: O&M Savings

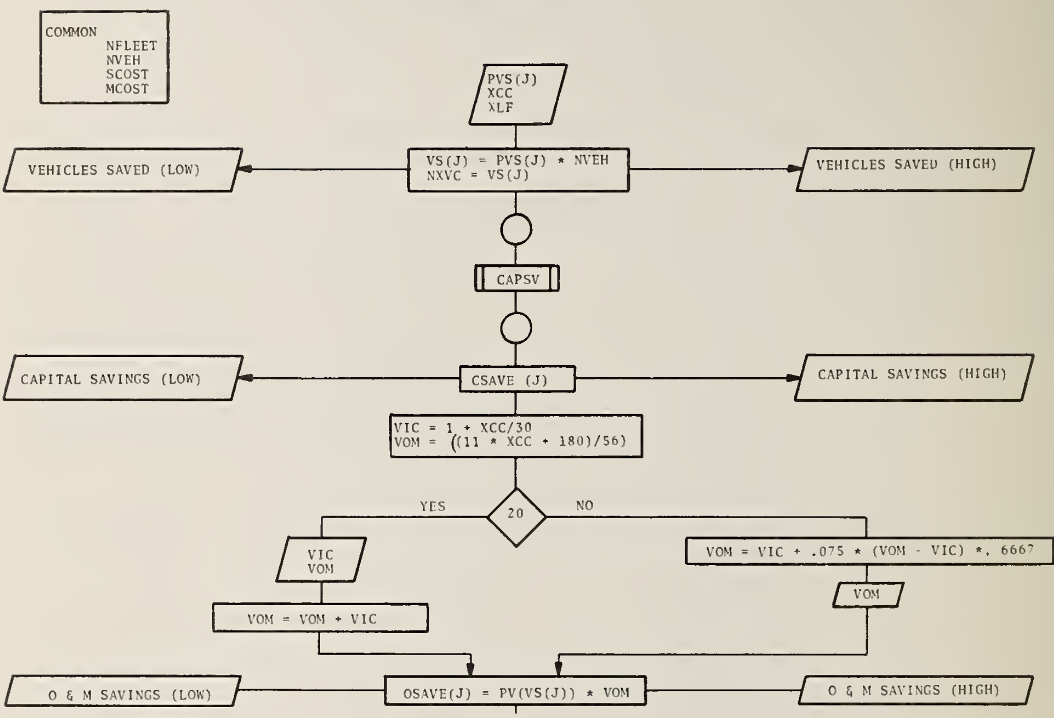
CALLS: Calls Per Caller Per Hour

CLRS: Number of Callers Required

CSAL: Average Annual Salary Per Caller

BEN:	Average Annual Benefits Per Caller
SOR(1):	Ratio of Benefits to Total Salary Per Caller
PVSAL:	Present Value of Total Salary For Callers
FORCE:	Driver Force
SAL:	Annual Driver Salary
BEN:	Annual Driver Benefits
SOR(2):	Ratio of Benefits to Total Driver Salary
ARATE:	Attrition Rate
REM:	Minimum Driver Force Required
PCUT:	Total Force Reduction
PSAVE:	Personnel Savings

GENERAL BENEFIT ALGORITHM



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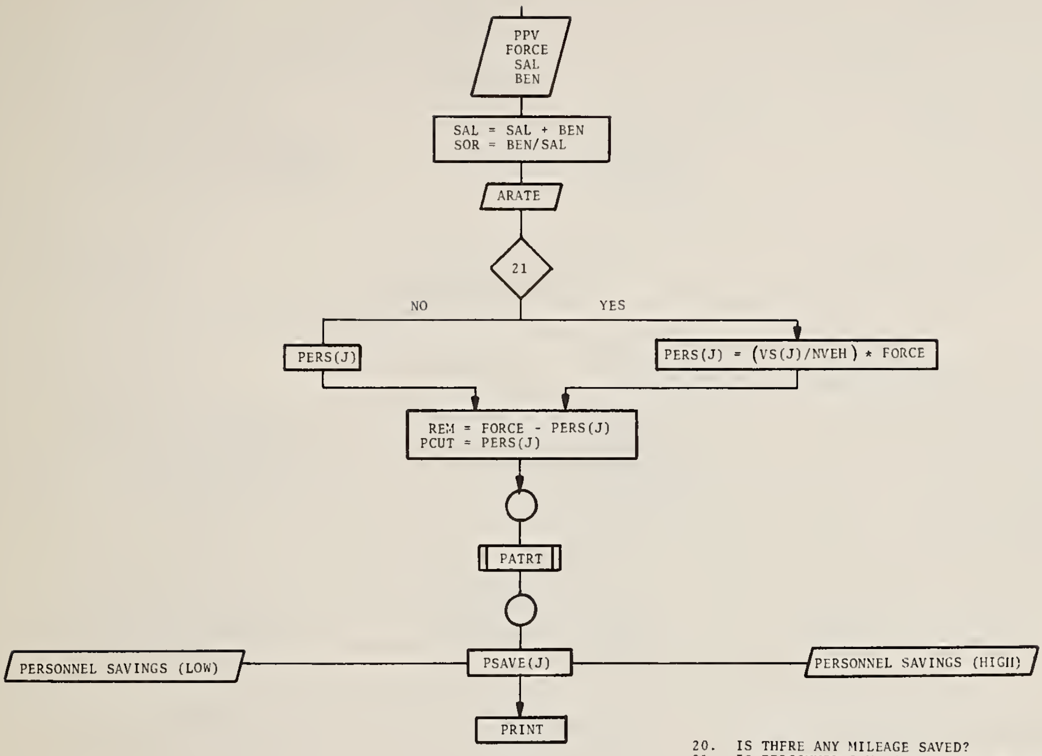


20. IS THFRE ANY MILEAGE SAVED?
21. IS PERSONNEL SAVING TO BE CALCULATED IN DIRECT PROPORTION TO VEHICLES SAVED?

(END FLOW DIAGRAM)

PRINT:

BENEFIT-COST SUMMARY FOR: GENERAL FLEET

	Low	High
% Savings	PVS(LO)	PVS(HI)
Vehicles Saved	VS(LO)	VS(HI)
Capital	CSAVE(LO)	CSAVE(HI)
O&M	OSAVE(LO)	OSAVE(HI)
Subtotal	CSAVE(LO)+OSAVE(LO)	CSAVE(HI)+OSAVE(HI)
Item B/C		
Single User	SUBTOTAL/SCOST	SUBTOTAL/SCOST
Multiple User	SUBTOTAL/MCOST	SUBTOTAL/MCOST
Personnel Saved	PCUT(LO)	PCUT(HI)
Salary	(1-SOR)*PSAVE(LO)	(1-SOR)*PSAVE(HI)
Benefits	SOR*PSAVE(LO)	SOR*PSAVE(HI)
Subtotal	PSAVE(LO)	PSAVE(HI)
Item B/C		
Single User	PSAVE(LO)/SCOST	PSAVE(HI)/SCOST
Multiple User	PSAVE(LO)/MCOST	PSAVE(HI)/MCOST
Total Savings	TOTAL ABOVE	TOTAL ABOVE
System Costs		
Single User	SCOST	SCOST
Multiple User	MCOST	MSCOST
Benefit-Cost Ratio		
Single User	TOTAL(LO)/SCOST	TOTAL(HI)/SCOST
Multiple Use	TOTAL(LO)/MCOST	TOTAL(HI)/MCOST

Detail Data for General Fleet

Percent Savings	PVS(LO)	PVS(HI)
Capital Savings	CSAVE(LO)	CSAVE(HI)
Estimated Annual Insurance Costs	VIC	
Estimated Total O&M Costs	VOM	

Full O&M Costs are Applied(1)

O&M Savings	OSAVE(LO)	OSAVE(HI)
Direct Personnel Saved	PCUT(LO)	PCUT(HI)
Average Cost per Person	SAL+BEN	
Personnel Savings	PSAVE(LO)	PSAVE(HI)

Ins. & Periodics are Applied(1)

O&M Savings	OSAVE(LO)	OSAVE(HI)
Direct Personnel Saved	PCUT(LO)	PCUT(HI)
Average Cost per Person	SAL+BEN	
Personnel Savings	PSAVE(LO)	PSAVE(HI)

(1) Output will vary, dependent on whether mileage is saved or remaining vehicles will travel more miles.

Key for General Benefit Algorithm

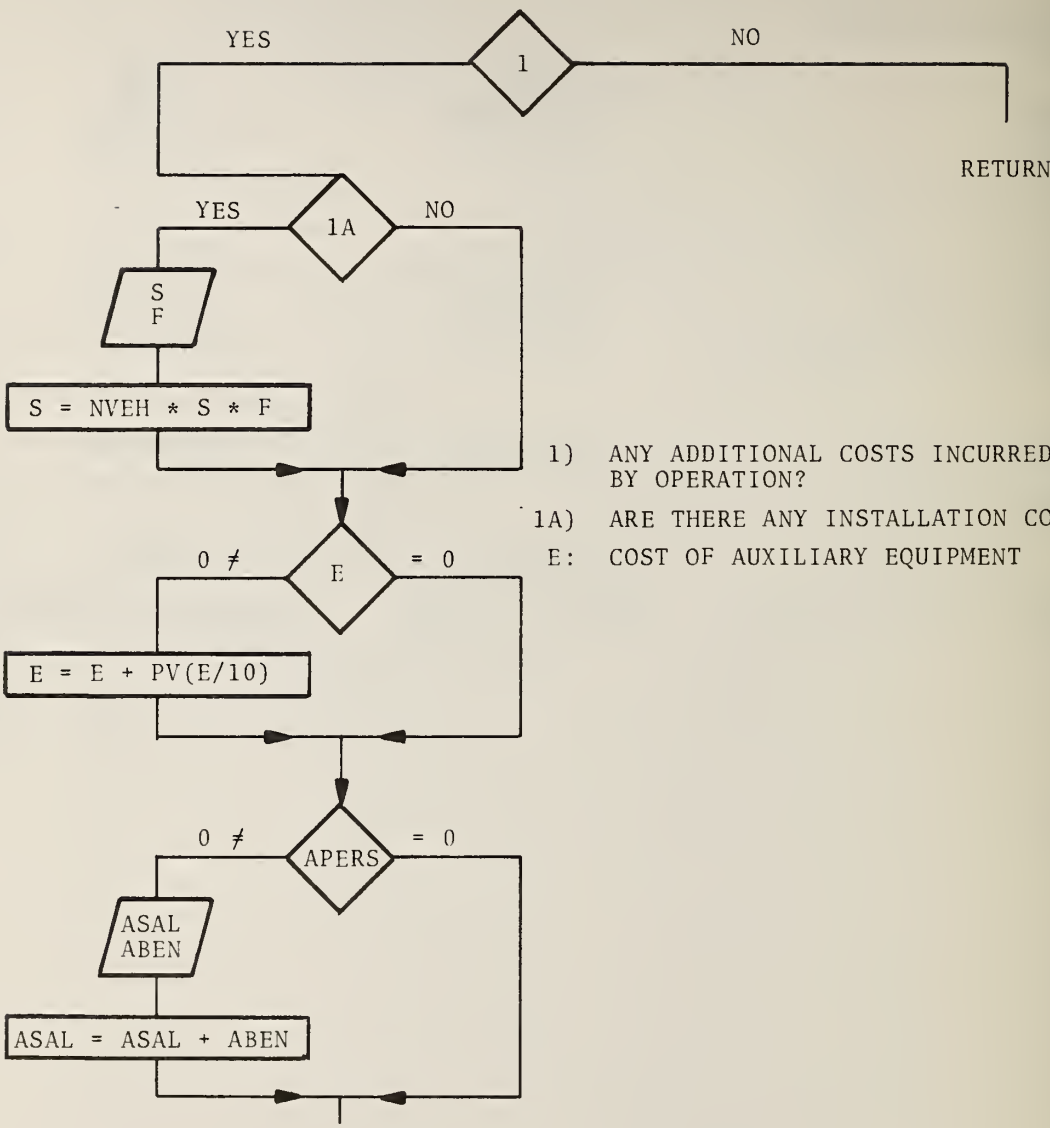
J:	Low, High Parameters
PVS:	% Estimated Savings Due to AVM
XCC:	Cost of New Vehicle, Less Salvage
XLF:	Vehicle Life
VS:	Vehicles Saved
CSAVE:	Capital Savings
VIC:	Annual Insurance Costs per Vehicle
VOM:	Annual O&M Costs per Vehicle
OSAVE:	O&M Savings
PPV:	Persons per Vehicle
FOXCE:	Initial Vehicle-Related Force
SAL:	Average Annual Salary
BEN:	Average Annual Benefits
SOR:	Ratio of Benefits to Total Salary
ARATE:	Attrition Rate
REM:	Minimum Required Work Force
PCUT:	Total Force Reduction
PSAVE:	Personnel Savings

PRINT:

BENEFIT-COST SUMMARY FOR: MULTI-USER

Savings Source	Low	High
User	TSAVE(LO)	TSAVE(HI)
User (for each User)	TSAVE(LO)	TSAVE(HI)
Capital Savings	ΣCSAVE(LO)	ΣCSAVE(HI)
O&M Savings	ΣOSAVE(LO)	ΣOSAVE(HI)
Personnel Savings	ΣPSAVE(LO)	ΣPSAVE(HI)
Total Savings	ΣTSAVE(LO)	ΣTSAVE(HI)
System Costs:		
Multi-User	MCOST	MCOST
Benefit/Cost Ratio	TSAVE(LO)/MCOST	TSAVE(HI)/MCOST

LOSS



1) ANY ADDITIONAL COSTS INCURRED BY OPERATION?

1A) ARE THERE ANY INSTALLATION COSTS?

E: COST OF AUXILIARY EQUIPMENT

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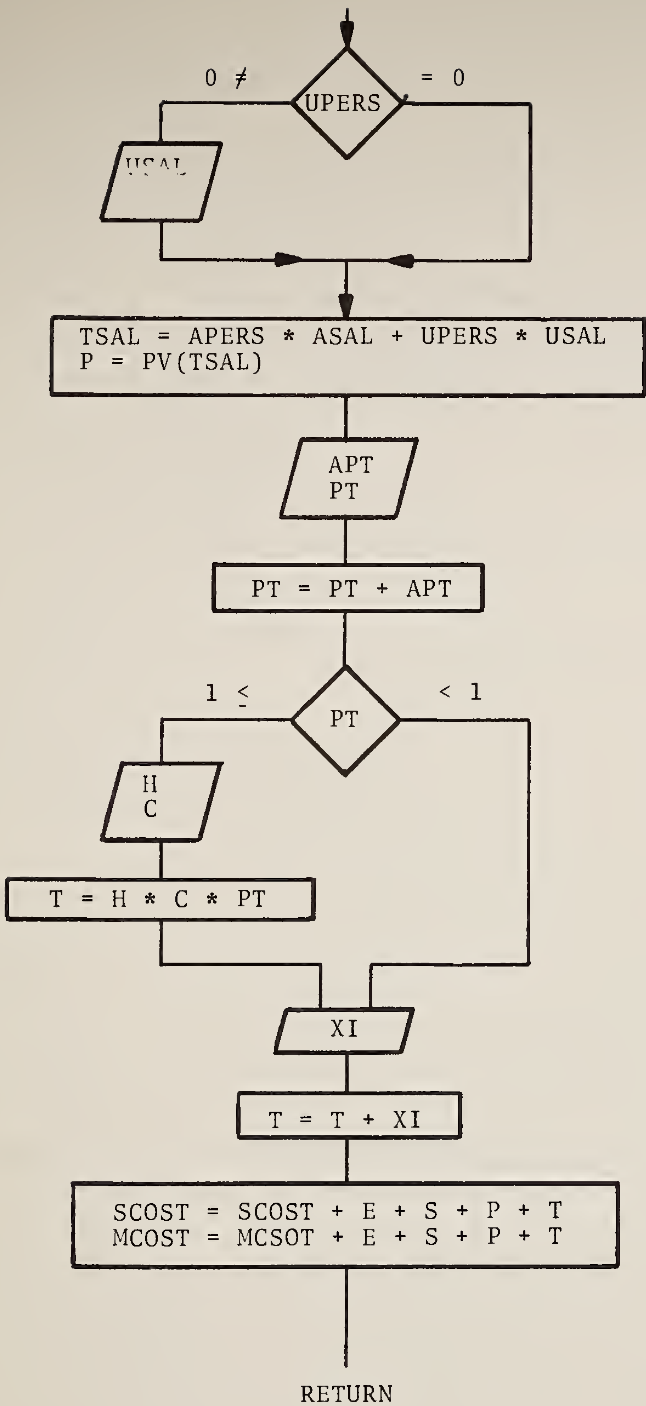


(END FLOW DIAGRAM)

Key for Loss Subroutine

S:	Installation Cost per Vehicle
F:	Fixed Installation Cost
E:	Additional Equipment Costs
APERS:	Number of Persons Added to Perform Additional Functions
ASAL:	Average Salary for Additional Personnel
ABLN:	Average Benefits for Additional Personnel
UPERS:	Number of Employees to Receive Increase in Salary for Additional Duties
USAL:	Additional Cost per Person
TSAL:	Total Additional Salary and Benefits to be Paid
PT:	Number of Persons to be Trained
APT:	Additional Personnel to be Trained
H:	Number of Hours of Training per Person Required
C:	Cost per Hour
T:	Total Cost of Training
XI:	Fixed Training Cost

VRAT

```
L = 0
J = LO,H1
L = L + 1
```

[RATIO TO COMPUTE VEHICLE SAVINGS DUE TO LAYOVER REDUCTION)

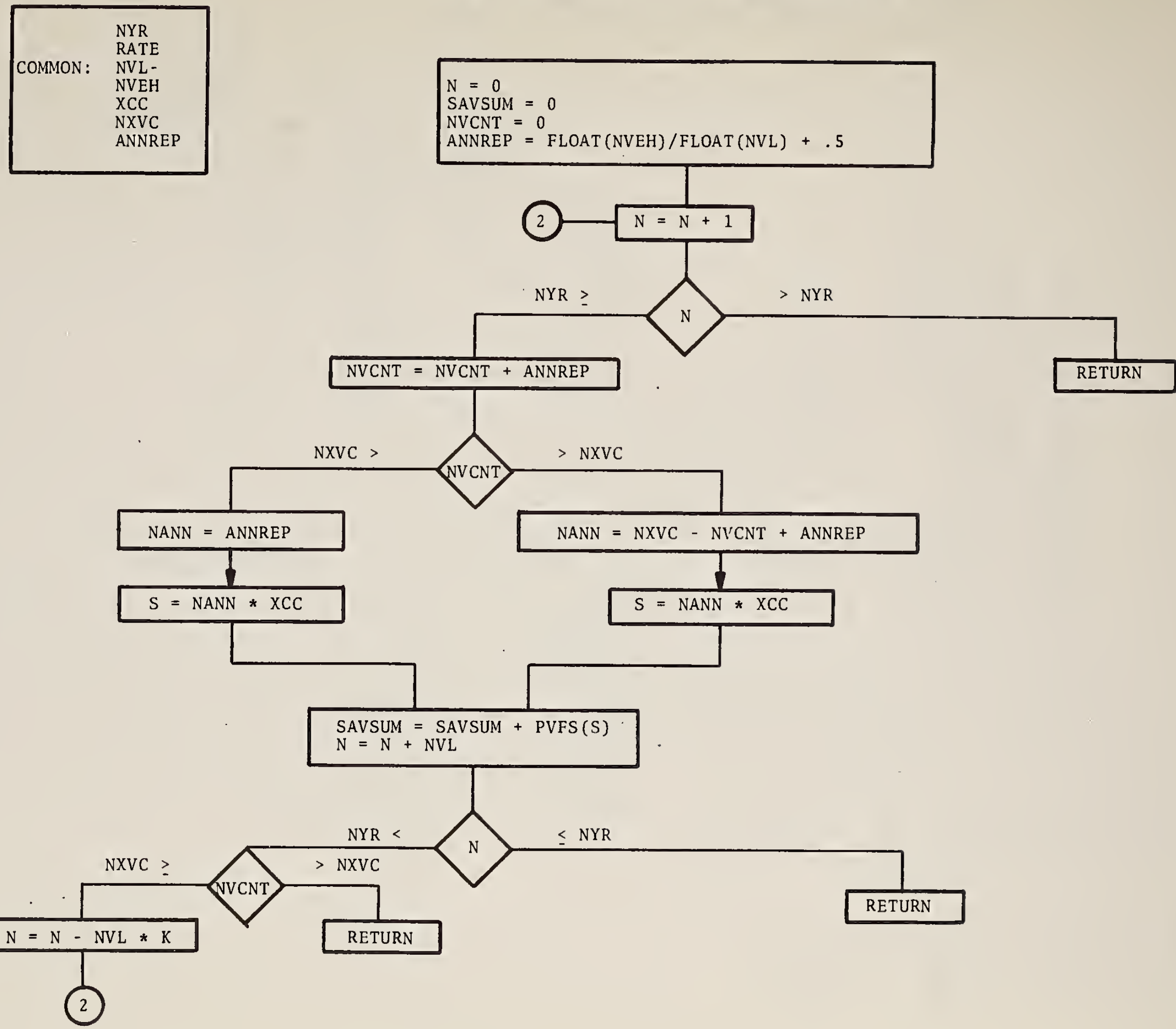
```
L = L + 1
VDAT(L) = VSR(J)*DAT(J)
```

[(RATIO TO COMPUTE VEHICLE SAVINGS DUE TO LOAD FACTOR IMPROVEMENT)]

```
L = L + 1
VDAT(L) = (1 - VSR(J)*DAT(J)
```

RETURN

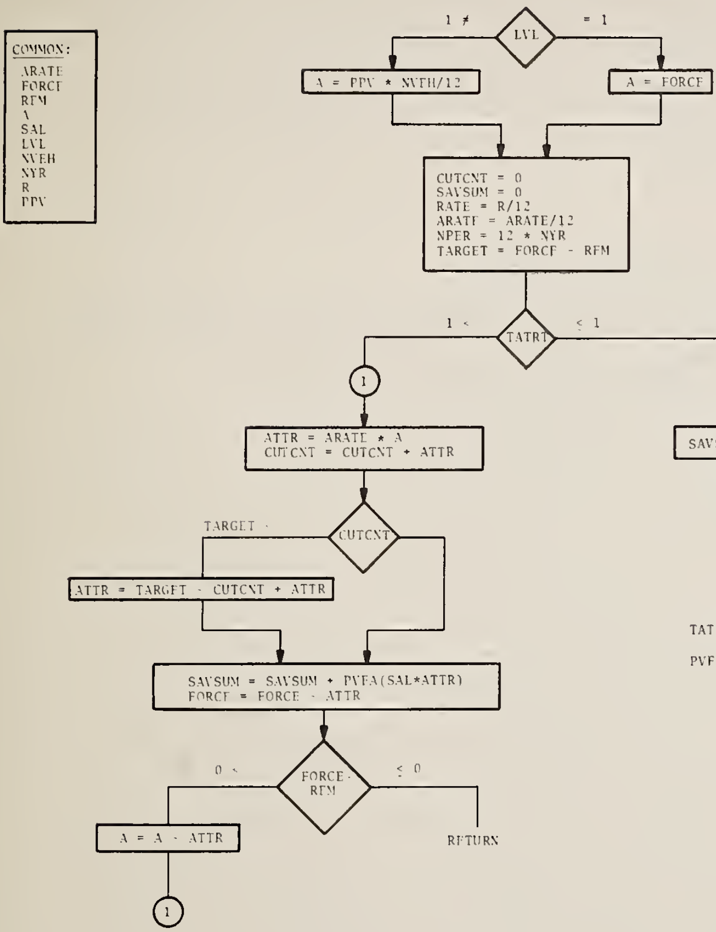
CAPSV - CAPITAL COST SAVING SUBROUTINE



Key to CAPSV Subroutine

NYR:	System Life
RATE:	Discount Rate
NVL:	Vehicle Life
NVEH:	Number of Vehicles in Fleet
XCC:	Capital Cost Per Vehicle, Less Salvage
NXVC:	Number of Vehicle to be Attrited
ANNREP:	Annual Replacement Rate
N:	Year Counter
NVCNT:	Vehicles Saved to Date
SAVSUM:	Present Value Summary of Vehicles Saved
NANN:	Vehicles saved in Year N
S:	Capital Savings

PATRT - PERSONNEL SAVINGS SUBROUTINE



TATRT = ALOG (1-(FORCE-REM)/A)/ALOG (1-ARATE)

PVFA(Y) = Y*((1-(1+RATE)$^{(-NPER-N+1)}$)
/RATE)/(1+RATE)^{n}

Key to PATRT Subroutine

TATRT:	Year in Which Target is Achieved
ARATE:	Attrition Rate
FORCE:	Initial Work Force
REM:	Minimum Work Force
A:	Attrition Base Force
SAL:	Average Annual Salary
SAYSUM:	Present Value Summary of Personnel Savings to Date
RATE:	Monthly Discount Rate
NPER:	System Life in Months
TARGET:	Attrition Goal
CUTCNT:	Total Attrition Achieved to Date
LVL:	Adjustments For Low and High Case Attrition Base Force
R:	Annual Discount Rate

APPENDIX C

BASE CASE MODEL INPUT-OUTPUT FORMATS

TYPE OF FLEET IS? BUS

INPUT NUMBER OF VEHICLES TO BE EQUIPPED? 2400

WH ‾ % OF THE BUS FLEET WILL BE EQUIPPED WITH PASSENGER COUNTERS? 5

IS THIS FLEET CURRENTLY EQUIPPED WITH VOICE RADIOS? YES

HOW MANY SQUARE MILES COVERED? 4\4\0

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 3825

FOR BUS :

	SHARP SIGNPOST	BROAD SIGNPOST (THOUSANDS OF DOLLARS)	RADIO FREQUENCY	DEAD-RECKONING
CAPITAL COST				
ON-VEHICLE EQUIP.	7146.0	2826.0	3906.0	9762.0
SIGNPOSTS	918.0	283.0	1032.9	688.5
REMOTE RECEIVERS	400.0	192.0	160.0	1708.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	29.0
VARIABLE	10.0	10.0	10.0	42.5
DATA PROCESSING				
BASIC	188.0	160.0	152.0	264.0
VARIABLE	620.0	390.0	130.0	1090.0
FLEET TOTAL	9302.0	3876.0	5400.9	13584.0
ANNUAL MAINTENANCE COSTS				
ON-VEHICLE EQUIP.	714.6	282.6	390.6	976.2
SIGNPOSTS	91.8	28.3	103.3	0.0
REMOTE RECEIVERS	40.0	40.2	37.0	191.8
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	2.9
VARIABLE	1.0	1.0	1.0	4.3
DATA PROCESSING				
BASIC	18.8	16.0	15.2	26.4
VARIABLE	62.0	39.0	13.0	109.0
TOTAL ANN. MAINT.	930.2	408.6	561.1	1310.5
PRESENT VALUE	5715.7	2510.7	3447.6	8052.7
PRESENT VALUE OF TOTAL COST:	15017.7	6386.7	8848.6	21636.7

THE LOWEST COST SYSTEM FOR BUS . AT $ 6386.7 THOUSAND DOLLARS,
IN COLUMN 2, THE BROAD SIGNPOST SYSTEM

ANALYSIS OF BENEFITS FOR BUS

PEAK LOAD FACTOR IMPROVEMENT IN % - IE, IF BUS NOW AVERAGES 20.0 PASSENGERS ON BOARD AND WILL IMPROVE TO AN AVERAGE OF 22.1, IMPROVEMENT % = 10.5. REASONABLE RANGE OF MAXIMUMS IS FROM 2% (BUSES WELL SCATTERED W/O AVM & LAT. BY NO MORE THAN 2 MINUTES 95% OF THE TIME) TO 69.9% (BUSES "BUNCH" BADLY W/O AVM, 95% LATENESS LEVEL IS 10 MINUTES). DEFAULT VALUES ARE 2% (LOW) AND 10% (HIGH).

LOW % HIGH %

IMPROVEMENT = 1,10

IT IS ASSUMED THAT 50.07% OF THE BUSES USED IN THE PEAK HOUR ARE DEPLOYED ON ROUTES WITH HEADWAYS OF LESS THAN 10 MINUTES. NEW VALUE?

IT IS ASSUMED THAT THE AVERAGE ONE-WAY RUN TIME ON A ROUTE IS 68.20 MINUTES. NEW VALUE?

LAYOVER TIME IS NOW 13.67 MINUTES PER ONE-WAY RUN. NEW VALUE?

THE DEFAULT GOALS ARE, 12.74 MIN. - LOW CASE AND 10.25 MIN. - HIGH CASE.

LOW HIGH

NEW VALUES ?

DEFAULT VALUE FOR INSURANCE COSTS IS $ 3200. PER VEHICLE PER YEAR. NEW VALUE?

TOTAL V&M COSTS INCLUDE INSURANCE AND PERIODICS PLUS PREVENTIVE MAINT. BASED ON MILES, ALL UNSCHEDULED MAINTENANCE, FUEL AND LUBRICANTS, AND OTHER COSTS SUCH AS TIRES, BATTERIES, ETC. WITH MILEAGE RELATED LIFE. THE DEFAULT VALUE IS $ 17120. NEW VALUE?

PART OF PERIODIC MAINTENANCE IS PERFORMED STRICTLY ACCORDING TO THE CALENDAR TO EACH VEHICLE (EG. SEASONAL, MONTHLY, DAILY). DEFAULT VALUE OF THE ANNUAL COST OF SUCH MAINTENANCE IS 7.5% OF TOTAL MAINT. NEW VALUE (IN DOLLARS)?

IT IS ASSUMED, FOR THE DEFAULT CASE, THAT THIS PROPERTY HAS A CHECKER FORCE OF 60. OF WHICH 20. WILL REMAIN ON TO PERFORM OTHER TASKS IN THE SAME DEPARTMENT. THE BALANCE WILL BE ABSORBED AT AN ATTRITION RATE OF, 10.%. EACH CHECKER HAS AN ANNUAL SALARY OF 15.00 THOUSAND DOLLARS. THE COST OF BENEFITS AND OVERHEAD ARE PRESUMED TO BE EQUAL TO THE SAME AMOUNT. YOU WILL HAVE A CHANCE TO REPLACE THESE VALUES.

PRESENT CHECKER FORCE ?

NUMBER TO REMAIN IN DEPARTMENT ?

ATTRITION RATE (IN %) ?

SALARY (IN THOUSANDS OF DOLLARS)?

BENEFITS AND OVERHEAD (IN THOUSANDS OF DOLLARS)?

NOTE: IN THE LOW CASE, THE ATTRITION IS LIMITED TO THE CHECKER FORCE ONLY; IN THE HIGH CASE, IT IS ASSUMED THAT THE CHECKERS CAN BE TRANSFERRED TO ANY ADMINISTRATIVE JOB, AND THE ATTRITION SPREAD OVER THE ENTIRE ADMINISTRATIVE STAFF.

IT IS ASSUMED THAT THERE ARE 2.0 DRIVERS PER BUS. IF THAT VALUE IS ACCEPTED, PRESS CARRIAGE RETURN; OTHERWISE ENTER TOTAL DRIVER FORCE.

WHAT PERCENT OF THE DRIVER PAYROLL IS OVERTIME? (DEFAULT VALUE IS 5%)

COST-BENEFIT SUMMARY FOR: BUS
(DOLLAR VALUES IN THOUSANDS)

SAVINGS SOURCE:		LAYOVER REDUCTION		LOAD FACTOR IMPROVEMENT	
		LOW	HIGH	LOW	HIGH
% CHANGE		6.8	25.0	1.0	10.0
VEHICLES SAVED		7.	22.	10.	91.
CAPITAL	$	375.5	1294.4	558.6	5302.8
O&M		70.5	562.7	751.4	5996.4
SUBTOTAL	$	446.0	1857.1	1309.9	11299.1
ITEM BENEFIT/COST:					
SINGLE USER		0.070	0.291	0.205	1.769
MULTI- USER		0.070	0.292	0.206	1.776
DRIVERS SAVED		12.	38.	17.	157.
SALARY	$	1034.8	3361.1	1539.2	13769.9
OVERHEAD+BEN		233.9	759.7	347.9	3112.2
SUBTOTAL	$	1268.7	4120.8	1887.1	16882.1
ITEM BENEFIT/COST:					
SINGLE USER		0.199	0.645	0.295	2.643
MULTI- USER		0.199	0.648	0.297	2.654

		DATA COLLECTION	
		LOW	HIGH
PERSONNEL SAVED		40.	40.
SALARY	$	1897.8	3665.8
OVERHEAD+BEN		1897.8	3665.8
SUBTOTAL	$	3795.6	7331.6
ITEM BENEFIT/COST:			
SINGLE USER		0.594	1.148
MULTI- USER		0.597	1.153
TOTAL SAVINGS	$	8707.4	41490.7
SYSTEM COSTS:			
SINGLE USER		6386.7	6386.7
MULTI- USER		6360.7	6360.7
BENEFIT/COST RATIO:			
SINGLE USER		1.363	6.496
MULTI- USER		1.369	6.523

TYPE OF FLEET IS? POLICE

INPUT NUMBER OF VEHICLES TO BE EQUIPPED? 1330

IS HIS FLEET CURRENTLY EQUIPPED WITH VOICE RADIOS? YES

HOW MANY SQUARE MILES COVERED? 475

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 0

FOR POLICE :

	SHARP SIGNPOST	BROAD SIGNPOST	RADIO FREQUENCY	DEAD-RECKONING
		(THOUSANDS OF DOLLARS)		
CAPITAL COST				
ON-VEHICLE EQUIP.	4322.5	1529.5	2128.0	5320.0
SIGNPOSTS	2812.0	1300.6	221.6	85.5
REMOTE RECEIVERS	40.0	24.0	16.0	168.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	0.0
VARIABLE	6.0	6.0	6.0	120.0
DATA PROCESSING				
BASIC	188.0	160.0	120.0	204.0
VARIABLE	372.0	234.0	78.0	654.0
F! ~~T TOTAL	7760.5	3269.1	2579.6	6551.5
ANNUAL MAINTENANCE COSTS				
ON-VEHICLE EQUIP.	432.3	153.0	212.8	532.0
SIGNPOSTS	281.2	130.1	22.2	0.0
REMOTE RECEIVERS	8.2	7.0	6.2	21.4
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	0.0
VARIABLE	0.6	0.6	0.6	12.0
DATA PROCESSING				
BASIC	18.8	16.0	12.0	20.4
VARIABLE	37.2	23.4	7.8	65.4
TOTAL ANN. MAINT.	780.2	331.5	262.6	651.2
PRESENT VALUE	4794.1	2037.1	1613.5	4001.5
PRESENT VALUE OF TOTAL COST:	12554.6	5306.1	4193.1	10553.0

THE LOWEST COST SYSTEM FOR POLICE AT $ 4193.1 THOUSAND DOLLARS,
IN COLUMN 3, THE RADIO FREQUENCY SYSTEM

```
ANALYSIS OF BENEFITS FOR POLICE

WHAT PERCENT OF MILES TRAVELLED BY THE POLICE ARE SPENT IN PREVENTIVE PATROL?
(DEFAULT VALUE IS 50.00%.)  NEW VALUE?

WHAT PERCENT OF MILES TRAVELLED IN RESPONSE TO CALLS WILL BE SAVED BY SENDING
THE CLOSEST CAR?
                              LOW %      HIGH %
DEFAULT VALUES                 2.00       10.00
NEW VALUES?

IT IS ASSUMED THAT O&M COSTS CONSIST OF THE COST OF OPERATIONS AND MAINTENANCE:
INCLUDING FUEL AND LUBRICANTS, SERVICE AND REPAIR AT A TOTAL RATE OF $ .183
PER MILE, WITH   27. THOUSAND ANNUAL MILES PER CAR; AND LIABILITY INSURANCE
(OR COST OF ACCIDENTS) AT $      0. PER CAR PER YEAR.  YOU WILL HAVE A
CHANCE TO REPLACE THESE VALUES.
     COST OF OPERATIONS AND MAINTENANCE PER MILE (IN DOLLARS)?

     ANNUAL MILES PER YEAR PER CAR (IN THOUSANDS)?

     THE ABOVE FACTORS YIELD AN ANNUAL COST OF MAINTENANCE PER CAR OF  4.941
     THOUSAND DOLLARS.  NEW VALUE?

     ANNUAL COST OF INSURANCE PER CAR (IN DOLLARS)?

IT IS ASSUMED THAT THERE ARE 3.3 PATROLMEN PER CAR EMPLOYED AT A SALARY OF
21.80 THOUSAND DOLLARS PER YEAR PER PATROLMAN.   BENEFITS AND OVERHEAD ARE
ASSUMED TO COST AN EQUAL AMOUNT.  THE DEPARTMENT'S ATTRITION RATE IS 10.00%
PER YEAR.  YOU WILL HAVE A CHANCE TO REPLACE THESE VALUES.
     PERSONS PER VEHICLE?

     PATROL FORCE = 4389. PERSONS.  NEW VALUE?

     ANNUAL SALARY (THOUSAND DOLLARS)?

     BENEFITS AND OVERHEAD (THOUSAND DOLLARS)?

     ATTRITION RATE?
```

COST-BENEFIT SUMMARY FOR: POLICE
(DOLLAR VALUES IN THOUSANDS)

SAVINGS SOURCE:	RESPONSE TIME REDUCTION	
	LOW	HIGH
% CHANGE	2.0	10.0
VEHICLES SAVED	11.	53.
CAPITAL	$ 109.6	580.9
O&M	323.0	1615.2
SUBTOTAL	$ 432.6	2196.0
ITEM BENEFIT/COST:		
SINGLE USER	0.103	0.524
MULTI- USER	0.104	0.529
PATROLMEN SAVED	35.	176.
SALARY	$ 4786.9	23332.8
OVERHEAD+BEN	4786.9	23332.8
SUBTOTAL	$ 9573.9	46665.7
ITEM BENEFIT/COST:		
SINGLE USER	2.283	11.129
MULTI- USER	2.305	11.235
TOTAL SAVINGS	$ 10006.5	48861.7
SYSTEM COSTS:		
SINGLE USER	4193.1	4193.1
MULTI- USER	4153.7	4153.7
BENEFIT/COST RATIO:		
SINGLE USER	2.386	11.653
MULTI- USER	2.409	11.763

TYPE OF FLEET IS? TAXI

INPUT NUMBER OF VEHICLES TO BE EQUIPPED? 800

IS THIS FLEET CURRENTLY EQUIPPED WITH VOICE RADIOS? YES

HOW MANY SQUARE MILES COVERED? 475

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 0

FOR TAXI :

	SHARP SIGNPOST	BROAD SIGNPOST (THOUSANDS OF DOLLARS)	RADIO FREQUENCY	DEAD-RECKONING
CAPITAL COST				
ON-VEHICLE EQUIP.	2600.0	920.0	1280.0	3200.0
SIGNPOSTS	2812.0	1300.6	221.6	85.5
REMOTE RECEIVERS	40.0	24.0	16.0	168.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	0.0
VARIABLE	4.0	4.0	4.0	80.0
DATA PROCESSING				
BASIC	188.0	160.0	120.0	204.0
VARIABLE	248.0	156.0	52.0	436.0
FLEET TOTAL	5912.0	2579.6	1703.6	4173.5
ANNUAL MAINTENANCE COSTS				
ON-VEHICLE EQUIP.	260.0	92.0	128.0	320.0
SIGNPOSTS	281.2	130.1	22.2	0.0
REMOTE RECEIVERS	6.8	6.1	5.3	20.5
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	0.0
VARIABLE	0.4	0.4	0.4	8.0
DATA PROCESSING				
BASIC	18.8	16.0	12.0	20.4
VARIABLE	24.8	15.6	5.2	43.6
TOTAL ANN. MAINT.	594.0	261.7	174.1	412.5
PRESENT VALUE	3649.7	1607.7	1069.5	2534.6
PRESENT VALUE OF TOTAL COST:	9561.7	4187.3	2773.1	6708.1

THE LOWEST COST SYSTEM FOR TAXI AT $ 2773.1 THOUSAND DOLLARS, IN COLUMN 3, THE RADIO FREQUENCY SYSTEM

A PORTION OF VEHICLE MILEAGE IS NON-REVENUE, DEAD-HEAD MILEAGE. THE DEFAULT VALUE IS 50.00%. NEW VALUE (%)?

IT IS ASSUMED THAT 18.00% OF TOTAL MILEAGE IS UNAVOIDABLE DEAD-HEADING, TRAVEL FROM THE DESTINATION OF LAST PASSENGER TO THE ORIGIN OF THE NEXT.
NEW VALUE (%)?

THE AVERAGE TAXICAB TRAVELS 50.000 THOUSAND MILES PER YEAR.
NEW VALUE (IN THOUSANDS)?

THE FACTORS ABOVE YIELD AN AVERAGE OF 20.500 THOUSAND MILES OF AVOIDABLE DEAD-HEADING PER YEAR. WHAT PERCENT OF THOSE MILES CAN BE SAVED BY DISPATCHING THE CLOSEST CAB TO EACH CALL AND OTHER DISPATCHING ECONOMIES DUE TO AVM?

	LOW %	HIGH %
DEFAULT VALUES	10.00	20.00

NEW VALUES?

TO PREVENT "HIGH-FLAGGING", AT A COST OF 0.470 THOUSAND DOLLARS PER TAXI (PRESENT VALUE DISCOUNTED OVER 10 YEARS), SEAT-PAD SWITCHES CAN BE INSTALLED AND CONNECTED TO THE AVM SYSTEM SO THAT THE DISPATCHER IS AWARE THAT A PASSENGER HAS ENTERED THE VEHICLE. IS THIS DEVICE TO BE INCLUDED?
ANSWER YES OR NO. NO

IT IS ASSUMED THAT O&M COSTS CONSIST OF THE COST OF OPERATIONS AND MAINTENANCE, INCLUDING FUEL AND LUBRICANTS, SERVICE AND REPAIR AT A TOTAL RATE OF $ .093 PER MILE, WITH 50. THOUSAND ANNUAL MILES PER CAR; AND LIABILITY INSURANCE (OR COST OF ACCIDENTS) AT $ 1475. PER CAR PER YEAR. YOU WILL HAVE A CHANCE TO REPLACE THESE VALUES.

COST OF OPERATIONS AND MAINTENANCE PER MILE (IN DOLLARS)?

THE ABOVE FACTORS YIELD AN ANNUAL COST OF O&M PER CAR OF $ 4.670 THOUSAND DOLLARS. NEW VALUE?

ANNUAL COST OF INSURANCE PER CAR (IN DOLLARS)?

DOES THE OPERATOR INCUR COST OF SALARY, BENEFITS OR OVERHEAD FOR ANY DRIVERS ON THE STAFF?

IT IS ASSUMED THAT THERE ARE 2.1 DRIVERS PER CAR EMPLOYED. THE AVERAGE DRIVER EARNS 7.63 THOUSAND DOLLARS PER YEAR IN COMMISSIONS. A FEW MAY GET ONLY MINIMUM WAGE, OR 4.8 THOUSAND DOLLARS PER YEAR. BENEFITS ARE 17.7% OF THE COMMISSION PAID, OR 1.35 THOUSAND DOLLARS PER DRIVER PER YEAR. THE COMPANY'S ATTRITION RATE IS 33.00% PER YEAR. YOU WILL HAVE A CHANCE TO PROVIDE DETAILED PERSONNEL COST INFORMATION.

DRIVERS PER VEHICLE?

DRIVER FORCE = 1680.
DRIVERS ON SALARY?

ANNUAL SALARY PAID BY COMPANY (THOUSANDS OF DOLLARS)?
NOTE: DO NOT INCLUDE COMMISSIONS. THE DEFAULT VALUE IS ZERO, OBTAINED BY A CARRIAGE RETURN.

DRIVERS RECEIVING BENEFITS? DEFAULT IS ENTIRE FORCE.

ANNUAL BENEFITS (IN THOUSANDS OF DOLLARS)?

OVERHEAD PER DRIVER (THOUSANDS OF DOLLARS)? DEFAULT VALUE IS ZERO.

ATTRITION RATE?

COST-BENEFIT SUMMARY FOR: TAXI
(DOLLAR VALUES IN THOUSANDS)

SOURCE OF SAVINGS:		"HIGH-FLAGGING" REDUCTION	
		LOW	HIGH
% CHANGE		0.0	0.0
		REDUCE DEAD-HEAD MILES	
% CHANGE		4.1	8.2
VEHICLES SAVED		33.	66.
CAPITAL	$	239.1	485.7
O&M		1238.5	2476.9
SUBTOTAL	$	1477.6	2962.7
ITEM BENEFIT/COST:			
SINGLE USER		0.533	1.068
MULTI- USER		0.585	1.174
DRIVERS SAVED		69.	138.
SALARY	$	0.0	0.0
OVERHEAD+BEN		581.5	1147.5
SUBTOTAL	$	581.5	1147.5
ITEM BENEFIT/COST:			
SINGLE USER		0.210	0.414
MULTI- USER		0.230	0.455
TOTAL SAVINGS	$	2059.1	4110.1
SYSTEM COSTS:			
SINGLE USER		2773.1	2773.1
MULTI- USER		2523.7	2523.7
BENEFIT/COST RATIO:			
SINGLE USER		0.743	1.482
MULTI- USER		0.816	1.629

```
IF, FOR ANY REASON, THIS SYSTEM IS NOT A FEASIBLE CHOICE TO GO INTO THE FINAL
WRAP-UP, YOU MAY CHANGE IT BY TYPING A DIFFERENT COLUMN NUMBER AFTER THE
QUESTION MARK.  A CARRIAGE RETURN WILL KEEP THE PRESENT CHOICE.?

ANSWER QUESTIONS ON COST-SHARING WITH 'YES' OR 'NO'.  QUESTIONS ON
'HOW MANY' SQUARE MILES OR ROUTE MILES MUST BE ANSWERED WITH A PORTION OF
THE SQUARE MILES AND ROUTE MILES COSTED FOR THE MULTI-USER CASE.  IF THAT
TOTAL IS EXCEEDED, YOU WILL GET AN ERROR MESSAGE AND MUST START THE SUB-
DIVISION OVER AGAIN.

DO ANY SERVICE AREAS (SQUARE MILES) OF DIFFERENT FLEETS OVERLAP ? YES

ANY AREA SERVED BY 3 USER(S) ? YES

HOW MANY SQUARE MILES? 475

SERVED BY BUS          ? YES

SERVED BY POLICE       ? YES

SERVED BY TAXI         ? YES

DO DIFFERENT FLEETS SERVE OVERLAPPING ROUTE MILES ? NO

ANY AREA SERVED BY 1 USER(S) ? YES

HOW MANY ROUTE MILES ? 2647

SERVED BY BUS          ? YES

SERVED BY POLICE       ? NO

SERVED BY TAXI         ? NO
```

TYPE OF FLEET IS? TOTAL

HOW MANY SQUARE MILES COVERED? 475

HOW MANY ROUTE MILES OUTSIDE OF SQUARE MILES ABOVE? 2647

FOR MULTI-USER :

	SHARP SIGNPOST	BROAD SIGNPOST	RADIO FREQUENCY	DEAD-RECKONING
	(THOUSANDS OF DOLLARS)			
CAPITAL COST				
ON-VEHICLE EQUIP.	14068.5	5275.5	7314.0	18282.0
SIGNPOSTS	3447.3	1496.4	936.4	562.0
REMOTE RECEIVERS	400.0	192.0	160.0	1708.0
COMMUNICATIONS				
BASIC	20.0	15.0	10.0	0.0
VARIABLE	20.0	20.0	20.0	242.5
DATA PROCESSING				
BASIC	188.0	160.0	120.0	204.0
VARIABLE	1240.0	780.0	260.0	2180.0
GRAND TOTAL	19383.8	7938.9	8820.4	23178.5
ANNUAL MAINTENANCE COST				
ON-VEHICLE EQUIP.	1406.9	527.6	731.4	1828.2
SI..POSTS	344.7	149.6	93.6	0.0
REMOTE RECEIVERS	88.0	55.2	49.0	254.0
COMMUNICATIONS				
BASIC	2.0	1.5	1.0	0.0
VARIABLE	2.0	2.0	2.0	24.3
DATA PROCESSING				
BASIC	18.8	16.0	12.0	20.4
VARIABLE	124.0	78.0	26.0	218.0
TOTAL ANN. MAINT.	1986.4	829.9	915.0	2344.9
PRESENT VALUE	12205.4	5099.3	5622.5	14408.3
PRESENT VALUE OF TOTAL COST:	31589.2	13038.2	14442.9	37586.8

THE LOWEST COST SYSTEM FOR MULTI-USER AT $ 13038.2 THOUSAND DOLLARS, IN COLUMN 2, THE BROAD SIGNPOST SYSTEM

IF, FOR ANY REASON, THIS SYSTEM IS NOT A FEASIBLE CHOICE TO GO INTO THE FINAL WRAP-UP, YOU MAY CHANGE IT BY TYPING A DIFFERENT COLUMN NUMBER AFTER THE QUESTION MARK. A CARRIAGE RETURN WILL KEEP THE PRESENT CHOICE.?

ANSWER QUESTIONS ON COST-SHARING WITH 'YES' OR 'NO'. QUESTIONS ON 'HOW MANY' SQUARE MILES OR ROUTE MILES MUST BE ANSWERED WITH A PORTION OF THE SQUARE MILES AND ROUTE MILES COSTED FOR THE MULTI-USER CASE. IF THAT TOTAL IS EXCEEDED, YOU WILL GET AN ERROR MESSAGE AND MUST START THE SUB-DIVISION OVER AGAIN.

COMPARISON OF COSTS

FOR EACH FLEET WITH THE LOWEST COST SYSTEM FOR THAT FLEET ALONE ON THE LEFT, AND EACH FLEET'S SHARE OF THE LOWEST COST MULTI-USER ALTERNATIVE ON THE RIG :

FOR: BUS	ALONE	SHARE OF MULTI-USER
	BROAD SIGNPOST	BROAD SIGNPOST
	(THOUSANDS OF DOLLARS)	
CAPITAL COST		
ON-VEHICLE EQUIP.	2826.0	2826.0
SIGNPOSTS	283.0	321.6
REMOTE RECEIVERS	192.0	174.3
COMMUNICATIONS		
BASIC	15.0	7.9
VARIABLE	10.0	10.0
DATA PROCESSING		
BASIC	160.0	84.8
VARIABLE	390.0	390.0
FLEET TOTAL	3876.0	3814.6
ANNUAL MAINTENANCE COSTS		
ON-VEHICLE EQUIP.	282.6	282.6
SIGNPOSTS	28.3	32.2
REMOTE RECEIVERS	40.2	50.3
COMMUNICATIONS		
BASIC	1.5	0.8
VARIABLE	1.0	1.0
DATA PROCESSING		
BASIC	16.0	8.5
VARIABLE	39.0	39.0
TOTAL ANNUAL MAINT.	408.6	414.4
PRESENT VALUE	2510.7	2546.1
PRESENT VALUE OF TOTAL COST:	6386.7	6360.7

FOR: POLICE	ALONE	SHARE OF MULTI-USER
	RADIO FREQUENCY	BROAD SIGNPOST
	(THOUSANDS OF DOLLARS)	
CAPITAL COST		
ON-VEHICLE EQUIP.	2128.0	1529.5
SIGNPOSTS	221.6	733.6
REMOTE RECEIVERS	16.0	11.1
COMMUNICATIONS		
BASIC	10.0	4.4
VARIABLE	6.0	6.0
DATA PROCESSING		
BASIC	120.0	47.0
VARIABLE	78.0	234.0
FLEET TOTAL	2579.6	2565.5
ANNUAL MAINTENANCE COSTS		
ON-VEHICLE EQUIP.	212.8	153.0
SIGNPOSTS	22.2	73.4
REMOTE RECEIVERS	6.2	3.0
COMMUNICATIONS		
BASIC	1.0	0.4
VARIABLE	0.6	0.6
DATA PROCESSING		
BASIC	12.0	4.7
VARIABLE	7.8	23.4
TOTAL ANNUAL MAINT.	262.6	258.5
PRESENT VALUE	1613.5	1588.2
PRESENT VALUE OF TOTAL COST:	4193.1	4153.7

FOR: TAXI	ALONE	SHARE OF MULTI-USER
	RADIO FREQUENCY	BROAD SIGNPOST
	(THOUSANDS OF DOLLARS)	
CAPITAL COST		
ON-VEHICLE EQUIP.	1280.0	920.0
SIGNPOSTS	221.6	441.2
REMOTE RECEIVERS	16.0	6.7
COMMUNICATIONS		
BASIC	10.0	2.6
VARIABLE	4.0	4.0
DATA PROCESSING		
BASIC	120.0	28.3
VARIABLE	52.0	156.0
FLEET TOTAL	1703.6	1558.8
ANNUAL MAINTENANCE COSTS		
ON-VEHICLE EQUIP.	128.0	92.0
SIGNPOSTS	22.2	44.1
REMOTE RECEIVERS	5.3	1.8
COMMUNICATIONS		
BASIC	1.0	0.3
VARIABLE	0.4	0.4
DATA PROCESSING		
BASIC	12.0	2.8
VARIABLE	5.2	15.6
TOTAL ANNUAL MAINT.	174.1	157.0
PRESENT VALUE	1069.5	964.9
PRESENT VALUE OF TOTAL COST:	2773.1	2523.7

ANALYSIS OF BENEFITS FOR MULTI-USER

COST-BENEFIT SUMMARY FOR: MULTI-USER
(DOLLAR VALUES IN THOUSANDS)

SAVINGS SOURCE:	LOW	HIGH
BUS	$ 8707.4	41490.7
POLICE	10006.5	48861.7
TAXI	2059.1	4110.1
CAPITAL SAVINGS	$ 1282.8	7663.7
O&M SAVINGS	2383.4	10651.2
PERSONNEL SAVINGS	17106.8	76147.7
LOSS ADJUSTMENTS	0.0	0.0
TOTAL SAVINGS	$ 20773.0	94462.6
SYSTEM COSTS:		
MULTI- USER	13038.2	13038.2
BENEFIT/COST RATIO:		
MULTI- USER	1.593	7.245

APPENDIX D

LOAD FACTOR IMPROVEMENT THEORY AND ANALYSIS

UNITED STATES GOVERNMENT

Memorandum

Arthur

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE
CAMBRIDGE, MA 02142

DATE: 7/9/76

SUBJECT: Reduction in Headway Variance

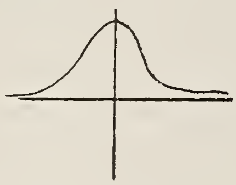
In reply refer to: 421

FROM: Arthur Priver/421

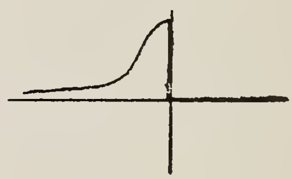
TO: Dave Reed/234

If a control strategy is applied to buses travelling along a route then the variance of the distribution of headways should be reduced in comparison with the variance that occurs when no control is applied. We will compute the variance reduction for the following specific control strategy. First, a bus is never allowed to leave a stop early. Second, a late bus always tries to catch up to get back on schedule.

Assume that a bus leaves a stop exactly on time and that its arrival time (and consequent departure time) at the next stop is normally distributed about the expected arrival time with a mean of zero and a variance σ_0^2. Then the departure time is given by a truncated normal distribution in which all values greater than 0 (i.e. early departures) are pushed back to 0:



becomes



The density function is given by

$$(1)\qquad f(x) = \begin{cases} \left(1/\sigma_0\sqrt{2\pi}\right) e^{-x^2/2\sigma_0^2} & -\infty \le x < 0 \\ 0 & 0 < x \le \infty \end{cases}$$

The mean of this distribution is given by

$$(2)\qquad \bar{x} = \int_{-\infty}^{\infty} x\, f(x)\, dx$$

$$\bar{x} = \frac{1}{\sigma_0\sqrt{2\pi}} \int_{-\infty}^{0} e^{-x^2/2\sigma_0^2}\, x\, dx$$

TSC F 1325.4 (4/73)

Let $u = -x^2/2\sigma_0^2$. Then $du = (-x/\sigma_0^2)dx$, so $x\,dx = -\sigma_0^2 du$.

Hence

(3) $$\bar{x} = \frac{-\sigma_0^2}{\sigma_0\sqrt{2\pi}}\int_{-\infty}^{0} e^{+u}\,du = -\sigma_0/\sqrt{2\pi}.$$

In order to compute the variance σ^2 of the truncated normal we also need to compute

(4) $$E(x^2) = \overline{x^2} = \frac{1}{\sigma_0\sqrt{2\pi}}\int_{-\infty}^{0} x^2 e^{-x^2/2\sigma_0^2}\,dx.$$

By symmetry and since if the integral went from $-\infty$ to ∞ the value would be σ_0^2, we have

(5) $$\overline{x^2} = \sigma_0^2/2$$

Thus

(6) $$\sigma^2 = \overline{x^2} - (\bar{x})^2 = \sigma_0^2\left(\frac{1}{2} - \frac{1}{2\pi}\right)$$
$$= \sigma_0^2\left(1 - \frac{1}{\pi}\right)/2.$$

The variance of the new headway distribution is reduced from the variance of the initial distribution by a factor of 1/2 $(1 - 1/\pi)$, which is approximately .341.

Computing the variance reduction at the next stop is very complicated, since it involves the convolution of a Normal with a truncated Normal distribution. In view of this difficulty, we will use the assumption that a late bus is trying to get back on schedule, and assume that the variance reduction computed above is the bound at each stop.

Let us now relate the above analysis to the impact on headway and the passenger load factor of keeping the same level of service, as measured by average passenger waiting time, with the computed variance reduction. First note that headway and passenger load factor are linearly related. The load factor (L) equals the number of passengers (P) divided by the number of buses (N). The number of buses is given by the total time (T) divided by the headway (h). Thus L = P/N = P/(T/h) = (P/T)h. Hence, an increase in headway of x% results in a corresponding x% increase in the passenger load factor.

Let h be the headway between buses, σ^2 be the variance of this headway, and W be the average passenger waiting time. We have our previous formula

$$W = \frac{h}{2} + \frac{\sigma^2}{2h}.$$

If we have an initial headway h_0 and variance σ_0^2 and have a new reduced variance σ^2, then for the same level of service (i.e., W = constant) we can compute the corresponding headway h:

$$W = \frac{h_c}{2} + \frac{\sigma_c^2}{2h_c} = \frac{h}{2} + \frac{\sigma^2}{2h}$$

Then,

$$h^2 - 2hW + \sigma^2 = 0$$

Solving this quadratic equation and using the constraints of motion gives us the single solution

$$h = W + \sqrt{W^2 - \sigma^2} .$$

(Note that if $\sigma = 0$ the average waiting time is half the headway, as expected).

From our earlier calculations, we know

$$\sigma^2 = \sigma_o^2 \left(1 - \frac{1}{\pi^2}\right)/2 ,$$

Thus,

$$h = \frac{h_c}{2} + \frac{1}{2h_c}\left(\sigma_c^2 + \sqrt{(h_c^2 + \sigma_c^2)^2 + \left(1 - \frac{1}{\pi^2}\right)\sigma_c^4}\right).$$

(Again, note that if $\sigma_c = 0$ then $h = h_o$).

Let us consider one representative case, and set σ_c = 1. Then, with 1 - $1/\pi^2$ = .8986788, we can compute the following table:

h_o	0.5	1	2	3	4	5	10
h	2.82	2.11	2.52	3.34	4.25	5.2	10.1
Inc. in load factor	464%	111%	26%	11%	6%	4%	1%

This table corresponds to a standard deviation of one minute in the headway. Empirical data from Chicago shows that the standard deviation is approximately the same magnitude as the headway, so the emphasis in using the above table should be placed around h_c = 1 and h_c = 2. Thus, the control strategy being considered gives a significant increase in the passenger load factor, even approaching 100% or more.

Arthur S. Priver

A. Priver

cc:
421/D. Lev
430/F. Tung
433/B. Blood
234/M. Roos

EXTENSION OF PRIVER CALCULATIONS TO LONGER STANDARD DEVIATIONS FOR 5 AND 10 MINUTE HEADWAYS

σ_o			
1	h_o	5	10
	h	5.2	10.1
	load factor increase	4%	1%
3	h_o	5	10
	h	6.9	10.9
	load factor increase	38%	9%
5	h_o	5	10
	h	10.53	12.6
	load factor increase	111%	26%
7	h_o	5	10
	h	16.13	15.3
	load factor increase	222%	53%
10	h_o	5	10
	h	28.2	21.1
	load factor increase	464%	111%

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